# AIRCRAFT AND AUTOMOBILE MATERIALS OF CONSTRUCTION

VOL II

NON-FERROUS AND ORGANIC MATERIALS

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## VOL. II

# NON-FERROUS AND ORGANIC MATERIALS

A TREATISE FOR AIRCRAFT, AUTOMOBILE, AND MECHANICAL ENGINEERS, MANUFACTURERS, CONSTRUCTORS, DESIGNERS, DRAUGHTSMEN, STUDENTS, AND OTHERS

BY

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# PREFACE

THE present volume is the second one of what is intended to be a fairly complete elementary treatise on the subject of engineering materials intended for automobile, aircraft, and general mechanical work. The first volume is confined to ferrous materials, whilst the present one covers the non-ferrous metals, timbers, and other organic materials. It is, of course, not possible to deal very fully with any one of the sections included (large treatises may be written on each of same), but it is hoped that the portions more useful to the engineer have been touched upon in most cases.

The information included in the present volume, which is necessarily of a somewhat miscellaneous or scattered nature, is based upon a number of specialist works, papers, proceedings, articles, manufacturers' catalogues, and data, and has been arranged in a more or less sequential order; thus, the metals are dealt with primarily, then the timbers, followed by organic and other materials, such as fabrics, dopes, paints, rubber, etc.

As in the case of the preceding volume, which was written for a special purpose, the metallurgical and highly technical sides have been made secondary to the general utility ones, so that the practical user of materials, the designer, draughtsmen, and others may obtain the greatest benefit with the minimum of unnecessary matter.

In order to render the treatment of the title subjects more complete, sections dealing with composite wooden constructions, plywoods, and veneers, and also one on the X-ray examination of materials, have been included.

Wherever possible, the standard specifications of materials have been given as fully as advisable, as it is believed that the data and information in such form a useful supplement to the matter in the main text.

The author, in conclusion, wishes to place on record his appreciation of the kindness of the various firms and individuals who have assisted in the compilation by furnishing diagrams, illustrations, information, and data ; in particular to the Royal Aeronautical Society, the Institution of Automobile Engineers, the Institution of Metals, the British Aluminium Company, the Delta Metal Co., Messrs. the Hoyt Co., Messrs. G. & J. Weir & Co., Ltd., Messrs. the Palmer Tyre Co., the Haskelite Manufacturing Corporation, the McGruer Hollow Spar Co., Messrs. Vickers, Ltd., the Tarrant Co., Messrs. Watsons, Ltd., Mr. A. Ryan, Dr. Rosenhain, Dr. Kaye, and others.

A. W. JUDGE.

London, 1921.

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# THE PROPERTIES OF AIRCRAFT AND AUTOMOBILE MATERIALS

## CHAPTER I

## ALUMINIUM AND ITS ALLOYS

### ALUMINIUM

ALUMINIUM is a white lustrous metal which is noted for its lightness and non-corrodible qualities; it is widely employed in automobile, aircraft, and electrical practice, and for many purposes in which weight economy, high conductivity, and non-corrodibility are essential, it is gradually replacing other materials such as steel, cast iron, copper alloys, and wood.

In the commercial form it can be obtained in a purity of from 98·5 to 99·0 per cent., but it is usually alloyed with small quantities of other metals, such as copper, nickel, zinc, and magnesium for hardening and strength improvement.

**Commercial Grades of Aluminium.**

The impurities found in ordinary aluminium consist of iron and silicon; the silicon may exist in one of two forms, namely: (*a*) combined with the aluminium as carbon is with iron, and (*b*) as an allotropic graphitoidal modification (analogous to the graphitic carbon in cast iron).

Other impurities which are sometimes found consist of copper, sodium, carbon, and occluded gases.

Commercial aluminium is generally classified in three grades, No. 1 being the purest, No. 2 for castings, and No. 3 for unimportant work.

The average compositions of commercial aluminium are given in the following table—

TABLE I.

COMPOSITIONS OF COMMERCIAL ALUMINIUMS. (Kent.)

| *Particulars.* | *Percentages.* | | | | |
|---|---|---|---|---|---|
| | *Aluminium* | *Silicon.* | *Iron.* | *Copper.* | *Lead.* |
| No. 1 Grade .. | 99·55 | 0·30 | 0·15 | — | — |
| No. 2 Grade .. | 96·0 | 2·0 | 2·0 | — | — |
| Aluminium Co. of America .. | 99·57 | 0·29 | 0·14 | — | — |
| Richards .. .. | 99·25 | 0·64 | 0·04 | 0·02 | 0·01 |

## Microscopic Structure of Aluminium.

Aluminium and its alloys are difficult to prepare for microscopical examination, owing to their soft character, readiness to scratch, and tendency to tarnish, probably by the formation of an hydrated oxide of aluminium, which it is very difficult to remove, without destroying the etched surface of the specimen.*

Specimens, in the initial rough state, may be sawn with a sharp hack-saw, but care is necessary in order to prevent surface distortion. To grind the specimen it is held lightly against a fast-running emery wheel, or it may be rubbed down on a smooth file. This is followed by rubbing down with increasingly fine emery papers, preferably by hand, the papers being held on a hard, flat surface. The liability of the emery particles to become embedded in the metal may be avoided by previously soaking the emery paper in paraffin. The method of polishing ground specimens is to use a rotating metal disc covered with a smooth surfaced woollen cloth of good quality, electrically driven, and fitted with means for varying the speed. The cloth covering is moistened with

* For a full account the reader is referred to "The Micrography of Aluminium and Its Alloys," D. Hanson and S. L. Archbutt. *Journ. Inst. of Metals*, April, 1919.

distilled water and powdered magnesia, and the specimen is held against it in such a way that it is rubbed at right angles to the scratches; the normal motor speed for this operation is about 500 R.P.M. The specimen in most cases will be found to be covered with very fine scratches in the direction of rubbing; these may be removed by washing the pad nearly free from polishing powder with distilled water, and again polishing at a lower speed.

The harder aluminium alloys do not exhibit scratches to any appreciable extent, and are relatively easier to polish.

Fig. 1.—Micrograph of Aluminium (Crystalline).

The final polishing should occur with the specimen held against the pad, but rotated in the opposite direction slowly, so that it is rubbed equally in all directions.

Iron occurs in aluminium as $FeAl_3$, which is almost insoluble in solid aluminium, and it is known that no sample of aluminium is absolutely free from this compound.

The presence of this iron compound is shown in unetched specimens as a white coloured constituent, with smaller and darker pieces of silicon (another impurity) embedded in a matrix of aluminium.

The structure of aluminium may be examined by treating the polished surface successively with caustic soda

(to combine with the metal) and nitric acid (to remove this compound).

Alternatively, caustic soda and aqueous hydrofluoric acid may be used.

Figs. 1, 2, and 3* show the structure of ordinary cast aluminium, and rolled aluminium, in the rolled and annealed states.

FIG. 2.—ALUMINIUM SHEET. ROLLED. MAGNIFIED 150 TIMES.

Fig. 1 shows that the structure of aluminium is minutely granular.

The effect of rolling is to give a distinct grain effect in the direction of rolling, which annealing effectively removes.

The following are the physical and mechanical properties† of commercial aluminium unalloyed with other metals—

### (a) Physical Properties.

Chemical Symbol: Al.

Atomic Weight: 26. Atomic Value: 10·6.

* J. Scott, and *Journ. Inst. of Metals*, April, 1919.

† The author is indebted to Messrs. The British Aluminium Co., Ltd., for this and much of the following information relating to the properties and applications of aluminium.

Position in Electro-chemical Series: 10.

Melting Point: 665° Centigrade or 1210° Fahrenheit.

Specific Heat (water = 1): 0·212.

Thermal Conductivity (silver = 100): 31·3.

Electrical Conductivity (silver = 100): 59·5.

Coefficient of Linear Expansion per ° C., = 0·0000245: or per ° F., = 0·0000136

FIG. 3.—ALUMINIUM SHEET, ANNEALED. MAGNIFIED 150 TIMES.

Specific Resistance in Microhms per cm. cu. at 68° F. (20° C.):
soft: 2·826
hard: 2·933

Specific Resistance in Microhms per cm. cu. at 0° C. (32° F.):
soft: 2·801
hard: 2·700

Resistance in Ohms per mil. foot at 68° F. (20° C.): 17·0

Resistance of Conductor 1000 yds. long × 1 sq. in. cross section
(ohms) soft: 0·04005
hard: 0·04158

Coefficient of Increase of Resistance with Temperature:
Per ° C.: 0·0032 to 0·0040
Per ° F.; 0·0018 to 0·0022

**(b) Mechanical Properties.**

Specific Gravity (Cast): 2·68.
" " (Rolled or Drawn), 2·71.

Weight per cubic foot (Cast): 167 lbs.
" " cubic foot (Rolled): 169 lbs.
" " cubic inch (Cast): 0·0944 lbs.
" " cubic inch (Rolled): 0·0969 lbs.

Tensile Strength (Cast): 5·8 tons per square inch.
" " (Rolled): 8·95 tons per square inch.

Elastic Limit (Rolled): 6·25 tons per square inch.

Modulus of Elasticity: 9,800,000 pounds per square inch.

**General Notes upon Aluminium.**

(*a*) Aluminium is unaffected by ordinary atmospheric influences but is corroded in sea-water. It is soluble in solutions of caustic alkalies and in hydrochloric acid. Ordinary washing soda (sodium carbonate) attacks aluminium; nitric, sulphuric, and hydrofluoric acids also slowly dissolve it.

When there is any excess of silicon present in the metal it does not withstand atmospheric corrosive actions.

Aluminium, when subjected to mechanical treatment, should be frequently annealed, the annealing temperature being about 400° to 480° C.

Aluminium should be melted in plumbago crucibles, such as those used for brass, and care must be taken not to overheat the metal. A reducing atmosphere is necessary, owing to the readiness with which the oxide forms; charcoal is a good fuel for heating purposes.

Aluminium is now used as a *deoxidiser* for iron and steel, and for keeping large melts of metal fluid, due to the reaction caused by the addition of aluminium to the melt. If aluminium is added in small quantities to molten iron or steel it combines with the oxygen and other gases absorbed

by the metal in the furnaces, and rises to the top in the form of slag, which can be skimmed off; the formation of blow-holes and defective castings is thus largely obviated. The amount of aluminium required for this purpose is about 10 ounces per ton of molten iron or steel.

When a small quantity of aluminium is present in cast iron, it serves to protect the silicon, manganese and carbon from oxidation.

Aluminium, even in small quantity, exerts a powerful protective action against the oxidation of silver zinc alloys.

When finely divided aluminium is heated in contact with powdered iron oxide, it combines with the oxygen of the latter and leaves the almost pure iron molten, with a great evolution of heat.*

For most metals aluminium is electro-positive, so that care is necessary that it does not come into contact, in aqueous solutions, with these metals, which include zinc, iron, nickel, lead, tin, copper, silver, gold, and platinum.

### Strength of Aluminium Wire.

Aluminium can be drawn out into fine wires, or beaten into fine leaves, owing to its great ductility; the tensile strength of wire of 0·128 inch diameter is about 11 to 12 tons per square inch, with an elongation in 48 inches of 0·30 to 1·02 per cent. and a reduction of area of from 75·0 to 83 per cent.

The tensile strength of commercial wire varies from 6·25 to 14·8 tons per square inch, according to the diameter and amount of drawing. The hard-drawn aluminium wires used for electric cable construction have a tensile strength of from 10 to 12 tons per square inch.

The following table indicates how the tensile strength varies with the size of the wire.

* This is the principle of the "Thermit" welding process, *see* Vol. I.

## TABLE II.

### Strengths of Aluminium Wires.

| *S.W.G.* | *Diam. (inches.)* | *Tensile Strength (tons per sq.inch)* | *S.W.G.* | *Diam. (inches.)* | *Tensile Strength (tons per sq. inch)* |
|---|---|---|---|---|---|
| 7/0 | 0·500 | 10·2 | 10 | 0·128 | 11·2 |
| 4/0 | 0·400 | 10·3 | 12 | ·104 | 11·6 |
| 0 | ·324 | 10·3 | 14 | ·080 | 12·0 |
| 2 | ·276 | 10·3 | 16 | ·064 | 12·5 |
| 4 | ·232 | 10·7 | 18 | ·048 | 12·9 |
| 6 | ·192 | 10·7 | 20 | ·036 | 14·3 |
| 8 | ·160 | 11·2 | | | |

Fig. 4 shows how aluminium wire behaves during a tensile test; it will be seen that there is no definite elastic limit, but the material continues to stretch for a maximum load of from 50 to 60 per cent. of the ultimate value.

The following are about the average strength values of commercial aluminium—

## TABLE III.

### Strength of Aluminium. (Kent.)

| *Condition* | *Elastic Limit (tons per sq.inch)* | *Tensile Strength (tons per sq inch)* | *Elongation. Per Cent.* | *Reduction of Area. Per Cent.* |
|---|---|---|---|---|
| Castings | 3·8 | 5·35–6·25 | 2–3 | 15 |
| Sheet | 5·58–11·20 | 10·7–17·9 | — | 20–30 |
| Wire .. | 7·15–14·70 | 11·2–29·10 | — | 40–60 |
| Bars .. | 6·25–14·70 | 12·5–17·9 | — | 30–40 |

The modulus of elasticity in the cast form is about 9,000,000 pounds per square inch, but for the sheet and wire forms varies from 8,800,000 to 10,700,000 pounds per square inch.

The strength of aluminium in compression for cast cylinders having a length equal to twice the diameter is about 5·4 tons per square inch, with an elastic limit of about 1·6 tons per

square inch. The maximum shearing stress value for castings is about 5·4 tons per square inch, and in the drawn condition about 7·15 tons per square inch.

**Effect of Temperature on Strength.**

The effect of increased temperature upon the strength of

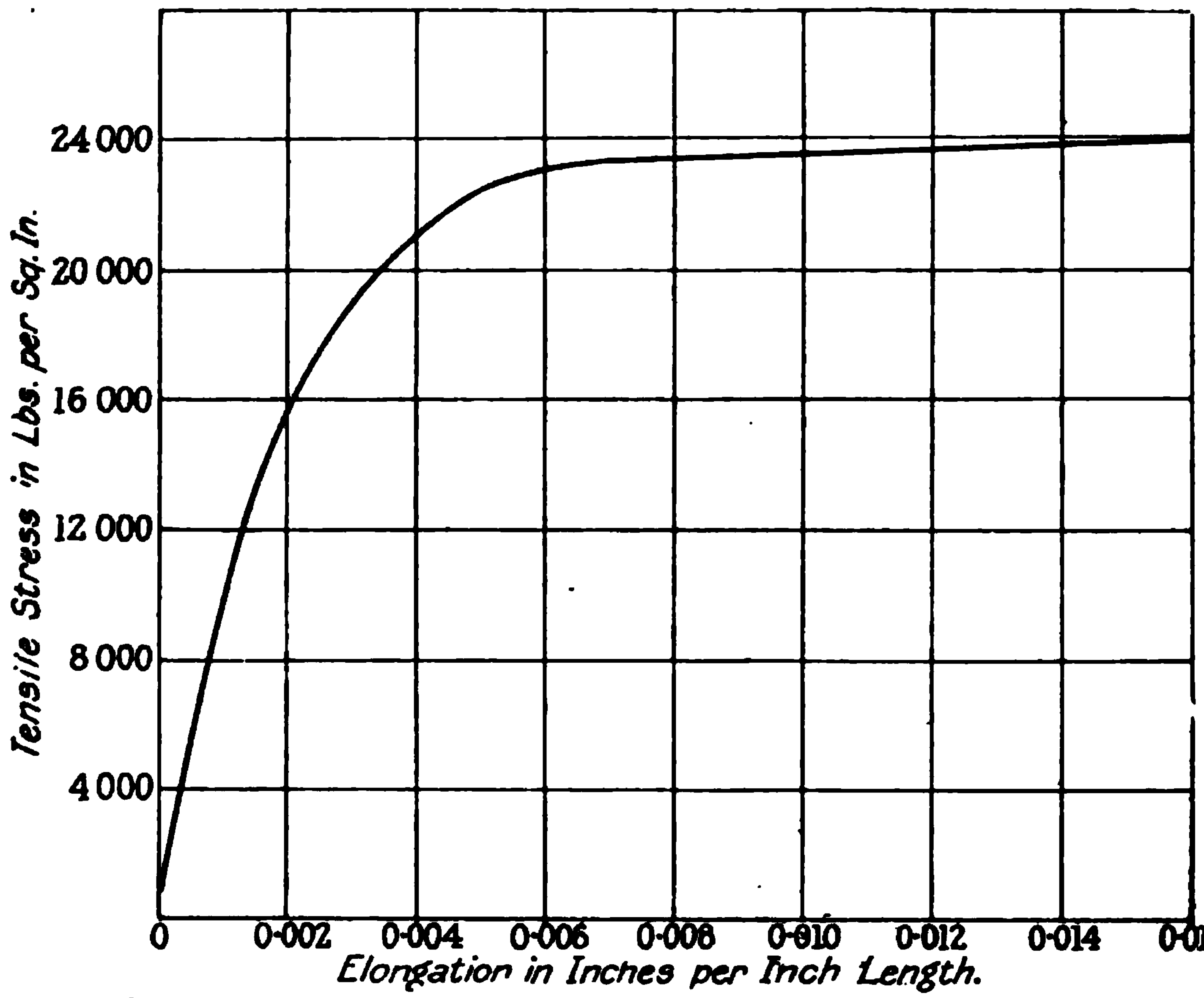



FIG. 4.—STRESS-STRAIN CURVE FOR ALUMINIUM WIRE.

aluminium is to progressively reduce it right up to the melting point, as the following results show—

TABLE IV.

EFFECT OF TEMPERATURE UPON THE STRENGTH OF ALUMINIUM. (Le Chatelier.)

| *Temp. °C.* | 15° | 100° | 150° | 200° | 250° | 300° | 400° | 450° | 460° |
|---|---|---|---|---|---|---|---|---|---|
| Tensile Strength in tons per square inch | 11·7 | 9·5 | 8·1 | 6·3 | 4·8 | 3·6 | 2·4 | 1·5 | 1·0 |

Aluminium is supplied commercially in the form of notched bars (the standard size weighing 3 pounds), rolled slabs (standard size, 74 pounds), round and square wire billets, bars, plates, sheets, tubes, sections of all shapes, beading, wire, cable, standard casting alloys, powder for paint, and in many other forms.

Aluminium is replacing copper for many electrical purposes, on account of its good electrical conductivity, weight economy, non-corrodibility, and lower cost; it is estimated that there is a minimum price economy of from 20 to 30 per cent. over that of copper. The specific gravity of annealed aluminium wire is 2·71, and that of copper 8·89, so that for the same volume copper is nearly 3·3 times as heavy as aluminium. The average conductivity of aluminium supplied for electrical purposes is 61 per cent. of that of copper, so that for the same length and resistance as that of copper, the sectional area will be 1·642 that of a copper conductor. It follows, then, that only about one-half the weight of aluminium is necessary, when it is employed for electrical purposes in place of copper, and as the price is only some 30 per cent. higher, there is a marked economy financially.

Amongst the numerous electrical applications of aluminium may be mentioned its employment for stranded overhead conductors, for bus-bars, feeders, connexions, for battery connexions (on account of its low immunity from action by acid fumes), large cables for underground power transmission, etc.

## Aluminium Sheet Metal Work.

Aluminium is admirably adapted to sheet-metal work, on account of its lightness, the ease with which it can be worked, and its low cost; with the exception of sheet-iron it is probably the cheapest metal on the market.

It can be obtained in a variety of grades, from dead-soft to hard-rolled, and each grade can be chosen so as to suit the requirement of the object to be made. Sheets may be

finished with any degree of polish or frosting, and the finish is more or less permanent.

The applications of sheet aluminium include aircraft engine cowling, fairing, panels and general body parts; automobile body work; railway coach work; lamps (spinnings); pressings, and numerous other work.

The following considerations refer to the different sheet metal work processes commercially employed—

### (1) Pressing.

Aluminium is particularly suited to punch-press, draw-press, and general press work, and, owing to its ductility a considerably deeper pressing may be produced in this metal than in brass or steel, and with a smaller expenditure of energy.

Commencing with a flat blank, a cylinder whose depth is 75 per cent. or more of its diameter can be drawn in one operation. The amount of annealing is also much less than with copper or iron; when drawing these latter metals, it is necessary to anneal after every two or three draws, and in the case of steel or brass the metal must be re-softened after every reduction, if used often. On the other hand, with aluminium, seven or eight drawings may be executed without any but the preliminary annealing, providing that ordinary care is taken in the die-manufacture.

Aluminium should never be worked without a lubricant. Ordinary paraffin (or kerosene) is probably the best lubricant for punch-pressings, and shallow draw press work. When drawing, the use of this lubricant prevents the dies from becoming "loaded" as the result of the abrasive action of the metal. For comparatively deep drawing, a thicker lubricant, such as lard, oil, or vaseline, may be employed.

### (2) Stamping.

No special treatment is required in stamping aluminium, and the average stamping machine operator can obtain results

equal to those using brass or steel. Aluminium will stand a deeper stamp than brass, and yet show no signs of pulling at the corners or roughening on the edge of the die.

For all pressed or stamped work it is necessary to employ the softest possible material. The sheets can be *annealed* by placing in a muffle at a temperature of 400 to 500° C., depending upon the gauge of the sheet. Ample time should be allowed for the metal to attain this temperature throughout, sustained heating at a low temperature being preferable to that carried out for a short period at a high temperature. Cooling, after heating, should occur as slowly as possible.

### (3) Spinning.

The softest sheets only should be used for spinning purposes. It will be found that aluminium is very easy to spin in the lathe on wooden or metal chucks, and, unlike copper, it does not harden so readily under the tool. Articles spun from annealed aluminium sheet are fairly hard when finished, but annealing during the actual process of spinning is seldom necessary.

The spinning speeds for aluminium vary up to 3000 to 4000 feet per minute (maximum), and vaseline or some similar grease should be used as a lubricant. In other respects aluminium requires no different treatment to that of other common metals.

Spun aluminium work is widely used for aircraft engine (rotary and radial) cowlings, propeller noses or "pots," control pulley casings, instrument cases, electric lamps, reflectors, etc.

### (4) Polishing.

Aluminium is capable of taking, and retaining, a high polish, equal to that of silver, without any special arrangements being required.

The polishing process closely resembles that employed for brass or German silver.

It is advisable to avoid the use of coarse abrasives, owing to the possibility of deep scratches occurring, but for rough castings No. 70 emery may be used for the preliminary cleaning. After this, a No. 120 emery should be employed, with a compressed canvas wheel, followed by No. 160 emery on a felt wheel. The final polish is imparted by buffing on a stitched cotton wheel, using a greasy tripoli compound, followed by treatment on a soft mop with dry lime or rouge.

For sheet metal work preliminary cleaning may be accomplished with the ordinary fine Trent sand and oil on a bob covered with leather, and running at a high speed. The second operation is that known as "grease-mopping," and is carried out on a calico mop, using tripoli compound. Finally, the articles are finished upon a soft mop, using dry lime.

For *castings* of a simple pattern, the polishing may be almost entirely accomplished by the *tumbling* process. For rough castings, coarse sand or crushed granite mixed with water to about the consistency of thin mortar may be used as a preliminary. This treatment, although somewhat harsh, is necessary, owing to the peculiar nature of the metal. When the castings have been sufficiently roughed, they are transferred to a wooden or wood-lined barrel, and *tumbled* with steel balls or smooth steel punchings in water containing ½ ounce of oxalic acid per gallon. This treatment requires from 2 hours to 2 days, depending upon the size and shape of the castings. The proper tumbling speed is that in which the articles roll around, and do not jump across the barrel.

After tumbling, the pieces are finished in the ordinary manner on a buff wheel.

The writer has found that *sand-blasting* is very suitable for cleaning and matt-finishing castings, besides being very much quicker than cleaning by tumbling.

### (5) Surface Finishing Processes.

The surface of aluminium may be finished either by *frosting*, *matting*, or *satin-finishing*, and *colouring*.

To give pure aluminium a fine *white, frosted appearance,* the metal or articles should be first cleansed from dirt or grease by washing in hot water or weak potash solution. An enamelled iron dipping bath should be selected, according to the size of the work to be frosted. White powdered caustic soda should be used in a cold water solution, and the solution should then be heated and kept at a temperature just under the boiling point whilst in use; it should be strong enough to blacken the aluminium when plunged in for a few seconds. A 5 per cent. solution will give about the correct strength for this purpose. For heavy frosting a bucket of salt is added to every 40 gallons of this solution. After frosting, the articles should be well washed in cold water and dipped in *aqua fortis* and then again washed in cold water. Finally, they should be dipped in hot water and dried in clean boxwood dust.

A finer *matt* or frosted appearance may be imparted by scratch-brushing the articles after the above treatment, using a soft wire scratch-brush run at a high speed.

A *satin finish* may be given to sheet aluminium articles by scratch-brushing with a fine steel brush run at a high speed. In this operation light, easy strokes are desirable, and the brush must be quite free from grease; an occasional splash of oil from the machine lubricator can be cleared by applying Sheffield lime to the brush.

*Sand-blasting* is very effective in rapidly producing a matt or satin-finish, according to the grade of sand and the pressure used.

*Colouring* of aluminium surfaces is rendered somewhat difficult on account of the fact that all of the chemical compounds of this metal are white. The following methods, however, enable a good black-bronze finish to be given to aluminium—

(*a*) The commonest method is to carefully clean the articles, and to then immerse them in a hot solution containing 8 ounces of white arsenic, 8 ounces of iron sulphate, ¾ gallon of hydrochloric acid and ¾ gallon of water. When sufficiently

blackened the articles should be removed, washed, and lacquered. A more adhesive deposit may be obtained by adding an ample quantity of ammonium molybdate and yellow prussiate of potash to the solution.

(*b*) Another method is to apply, by means of a camel-hair brush, a neutral or alkaline solution of cobalt nitrate to the articles. On heating, the colour of the surface changes and gradations ranging from steel grey to black are obtained, depending upon the temperature of heating.

**The Machining of Aluminium.**

Owing to the softness of pure aluminium, rather more care is required in machining it, as the tool is liable to tear and drag the metal. Pure metal is, however, seldom used for parts requiring machining and some form of alloy is generally employed. Special alloys of good machining qualities are supplied by the British Aluminium Co., and others.

In turning, drilling, or milling, a high speed should be employed and the tools should have acute cutting edges. It is advisable to finish sharpening all tools on an oil-stone, as a keen edge is very desirable. When turning or boring, a pointed tool with a large top clearance should be employed.

The lubricant plays an important part when machining aluminium. For general work, paraffin oil is much used. Turpentine is favoured in some quarters, but this is not recommended when tapping or screwing, as the liquid leaves a resinous deposit when it evaporates, which is apt to cause the screw to bind. When drilling or tapping, some machinists prefer to use beeswax rubbed on the tool as a lubricant.

In milling, the best results are obtained by the use of a built up tool, consisting of a number of cutters inserted in a cast iron head. These cutters should be ground with sharp corners; rounded corners are objectionable and prevent a good finish. The cutters should only cut at the extreme points and not have a scraping action as with brass. The distance between successive cutters should be from 2 to 6 inches, so

as to eliminate the clogging effect of the chips. To obtain a mirror-bright surface when milling, paraffin has been recommended as a lubricant. Cutter speeds of 500 to 600 feet per minute are commonly used.

When grinding aluminium the wheel should first have a piece of paraffin wax held against it to fill up the pores. A wheel so treated will not cause the metal to adhere to it and will not require to be so frequently dressed. Any kind of grinding wheel may be used, emery, corundum, carborundum, etc., but crystolon wheels are said to give the best results.

Filing should always be done with a single-cut file, which may easily be cleaned with a wire brush. Cross-cut files are readily clogged.

### Electrolytic Deposition, or Plating of Aluminium.

Aluminium is not an easy metal to deposit other metals upon owing to the presence of an invisible film of oxide or hydrated oxide upon the surface. In the ordinary way, electrically deposited metal will not adhere to aluminium for any length of time, but will crack and flake off.

It is, therefore, of essential importance to thoroughly clean the surface of aluminium, and for this purpose a dilute solution of hydrofluoric acid is satisfactory; the metal should remain in this liquid until the surface is slightly roughened, and should then be rinsed in water. Finally, it should be dipped in a mixture of sulphuric acid and nitric acid in the proportions of 4 to 3 for a few seconds, after which it should be thoroughly rinsed in clean water; the metal will then present a very clean and white surface.

It has been found that zinc is one of the best metals for adhering to aluminium, and for this reason it is used as a base-metal upon which others are deposited.

When aluminium has to be plated with gold, it should be first given a zinc deposit, and then a copper one, and, finally, the gold coating; the reason for this procedure is that gold and zinc alloy well together as a light coloured metal, and it

therefore requires a relatively much greater quantity of gold to give the desired appearance.

For zinc-plating aluminium, the solution should consist of a mixture of zinc and aluminium sulphates, slightly acidified, and having a density of about 15° Beaumé; it is found that a much better coating is obtained if about 1 per cent. of hydrofluoric acid or potassium fluoride is added to the solution,* as the formation of oxides upon the aluminium is prevented thereby.

The current density required is about 10 to 20 amperes per square foot, and ordinary articles require from 10 to 15 minutes for zinc coating.

**Casting of Aluminium and Its Alloys.**

Aluminium castings are now very widely employed in aircraft and automobile engineering work, and their uses are extending.

Provided that the proper precautions are observed in the design of the castings, the correct moulding and pouring operations, etc., it is possible to produce practically any type of casting, from complicated monobloc cylinder castings complete with part of the crank-case, and massive crank-cases weighing 1 cwt. or more, to thin castings having a large superficial area and a thickness of only $\frac{1}{8}$ inch, as in motor body panel work. It is usual to alloy the metal with small quantities of other metals, such as copper, nickel, manganese, iron, zinc, or magnesium, in order to obtain improved strength and hardness. The properties of a number of suitable alloys are given subsequently in the present chapter, and Table V shows the properties of the British Aluminium Co.'s standard casting alloys. Of these alloys, those known as No. 6, No. 6*a*, and No. 12 are most commonly adopted. The first two are supplied for sand casting; No. 6 has been evolved to give particularly clean and strong castings (having a tensile

* "Electrochemical Industry," Vol. II, p. 85. C. F. Burgess and C. Hambuechen.

strength of about 11 tons per square inch) which are easily machined and readily polished.

Alloy No. 6*a* is slightly heavier than No. 6, but casts rather better, and is perhaps the more widely used of the two. The third alloy, No. 12, is the heaviest of these three light alloys, and is suitable for producing castings requiring extra stiffness or hardness, or for the production of chill castings.

In connexion with these alloys, care should be taken not to overheat them, or to pour them at too high a temperature. The alloys in question have melting points of about 610° C. or 1130° F.) and should be poured at a temperature below 665° C. (or 1225° F.), it being preferable to pour the metal as soon as it is melted. It should be well stirred and skimmed before pouring, and it is better to use a high-pressure, gas-fired furnace, using graphite and plumbago crucibles in preference to iron.

## TABLE V.

### Properties of B.A. Standard Casting Alloys.

| *Alloy No.* | *Specific Gravity.* | *Weight per cubic foot pounds.* | *Average Tensile pounds per square inch* | *Elongation on 2 inches per cent.* | *Uses.* |
|---|---|---|---|---|---|
| 4 | 2·78 | 173 | 16000 | 7·5 | This alloy makes castings which will afterwards rivet or take a set, so that it is an admirable substitute for soft brass. It is also eminently suitable for bolts and nuts, and for sections requiring stiffness. Its tensile strength is improved by working, and its surface will take a good polish. |
| 6 | 3·01 | 187 | 25000 | 3·0 | This alloy is designed to give specially clean castings (for all round work) which are easily machined and highly polished. |
| 6*a* | 3·14 | 196 | 29000 | 1·0 | Casts easier than No. 6, but is slightly heavier. It will take a very high polish. |
| 12 | 2·84 | 177 | 25000 | 3·1 | Designed for die-castings or castings requiring extreme stiffness. |
| 22 | — | — | — | — | — |
| 31 | — | — | — | — | — |
| 50B.B. | 2·75 | 171 | 25000 | 12·0 | Specially suitable for Mathematical and Optical instruments or small intricate castings. Castings can be bent. |

Fig. 5 shows a good example of intricate coring work in the case of a cast aluminium ventilator for an electric motor. Figs. 6, 7, and 8 are illustrations of typical aluminium castings.

**Casting Information.**

. In the casting of aluminium, one of the most important factors affecting the strength and other properties is that of the correct melting and pouring temperature. The metal

FIG. 5.—SHOWING AN INTRICATE ALUMINIUM CASTING (ELECTRIC MOTOR VENTILATOR).

may be easily overheated, and if this takes place the castings are unsatisfactory. The melting point, which is 625° C. (or 1160° F.) for pure aluminium, should never be exceeded, and in this connexion the use of pyrometers or of automatic heat regulators, or thermostats, such as that described in Vol. I of this work, are invaluable. The correct melting temperatures for the alloys should be ascertained beforehand; copper, manganese, and nickel alloys have a higher, and tin and zinc alloys a lower melting point than that of the pure aluminium.

When molten, the dirt and oxide should be carefully removed by skimming; if possible, a reducing atmosphere

Fig. 6.—Examples of Aeroplane Engine Castings in Aluminium Alloy

Fig. 7.—Radiator and Induction Pipe Castings in Aluminium Alloy.

should be employed. Stirring the molten metal renders it more uniform. Plumbago crucibles should be employed, and in this connexion it is useful to note that an ordinary 500 pounds brass pot will take about 140 pounds of aluminium.

The pouring of the metal should preferably take place from the bottom of the crucible, and should be done at as low a temperature as possible for the strongest castings; the metal

FIG. 8.—THE NAPIER LION AEROPLANE ENGINE. AN EXAMPLE OF THE USE OF ALUMINIUM CASTINGS.

forms a very fluid melt, and is therefore easily poured. It should be cooled down to a dull red by adding a few pieces of aluminium to the ladle, thoroughly stirred and skimmed (when poured from the top) and poured in a steady stream, rapidly for green-sand and slowly for chill-moulds. The moulds should be loosened as soon as possible after pouring.

The moulds should be made of green-sand for the best quality of work, and only lightly rammed. Plumbago or French chalk is employed for facing purposes.

Cores are often mixed with sawdust and a resin binder, and this allows them to soften and readily crush as the metal cools; these cores must be knocked out hot, otherwise they will stick to the metal. With hard cores the castings are liable to crack, due to the shrinkage of the metal.

Vertical risers and ample sized gates are essential to good work. Where possible a U- or syphon-shaped gate should be employed.

The patterns should have an allowance of $\frac{13}{64}$ inch per foot for the shrinkage of the metal, and should avoid complicated coring and thin sections. Sudden changes of section should also be avoided, as the smaller parts cool the more rapidly, and shrinkage stresses occur. Ample fillets must be provided in pattern work.

Castings may be cleaned* either by sand blasting, tumbling, scratch-brushing, or dipping in caustic soda or urine.

### Chill Castings.

The process of casting in metal moulds instead of in the ordinary sand moulds is very satisfactory and economical for similar parts which are required in large numbers; by suitably designing the mould, the final machining may either be in part avoided or reduced to a minimum.

The same mould may be used for thousands of castings, if wiped or blown out after each two or three castings, and the castings themselves possess a greater strength, hardness, and ductility over sand castings. Little or no machinery is required, and even small holes may be accurately cast; it is also easily possible to cast toothed wheels, bevels, racks and pinions, and similar parts with sufficient accuracy for most purposes. Parts required for instruments, such as speed indicators, revolution counters, compasses, etc., are usually chill or die cast.

Alloys of aluminium with zinc, although very suitable for

* *See also* p. 13.

sand casting, are not recommended for chill castings, since they are liable to absorb iron from the moulds.

The most successful alloys for chill castings are those containing from 4 to 10 per cent. of copper ; a small percentage of manganese also adds to the ductility of the casting and improves the strength at high temperatures.

The moulds should be lubricated with beeswax or tallow, and should be cleaned out after each two or three pourings either by wiping or with an air-blast.

The pouring should be done slowly, and the temperature of the melted aluminium kept as low as possible ; the finished casting should be removed as soon as possible from the mould.

**Semi-Die Castings.**

In many cases these castings offer advantages over chill or die castings. The process consists in casting the alloy in a metal chill, with a sand core, so that the inside of the casting is against sand, and the outside against the metal mould. The method is employed for castings in which it is impossible to design simple cores which can be readily withdrawn. If the sand core is made sufficiently "fragile," in semi-die casting, it may not be necessary to remove the casting from the chill very quickly, especially if the gates and risers are so arranged that all of the contraction occurs in the core.

Aeroplane engine pistons are sometimes made by this method.

**Die Castings.**

The process of die casting differs from that of chill casting, in that the fluid metal is cast under pressure, so that it very accurately takes up the mould impressions.

The pressure employed may be either hydrostatic, that is, due to a high head or column of the molten metal, pneumatic, or centrifugal.

Special die casting machines are now employed for rapidly

dealing with the metal. In most cases the metal is melted in a special machine to the top of which the dies are fixed. By the movement of a lever, or some similar means, the molten metal is forced by pneumatic pressure into all the

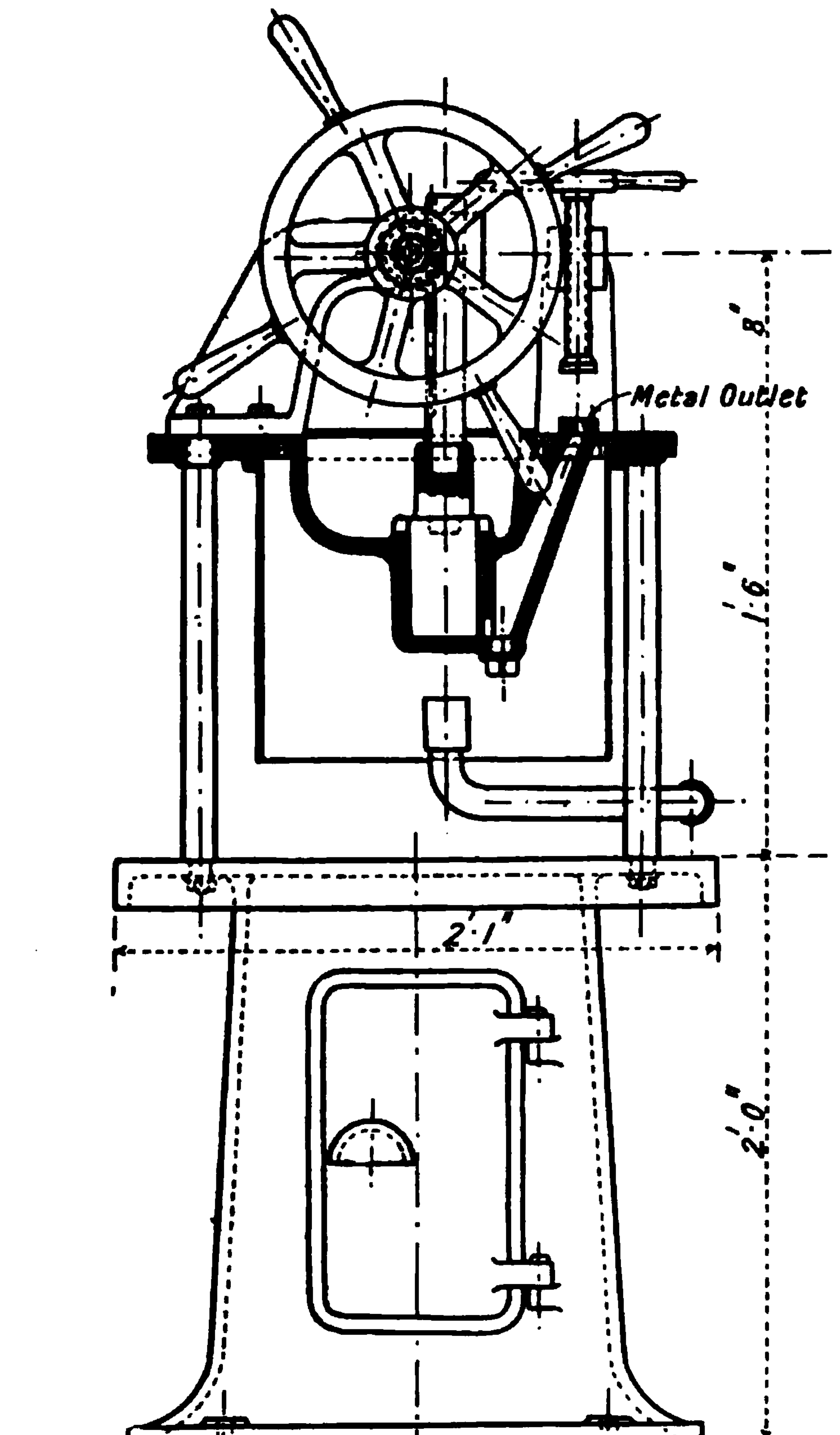



FIG. 9.—DIE-CASTING MACHINE.

interstices of the steel die, and almost immeditaely afterwards a second lever is pulled, which opens the dies and ejects the finished casting.*

The machines shown in Figs. 9 and 10 are especially suitable

* The Monometer Co.

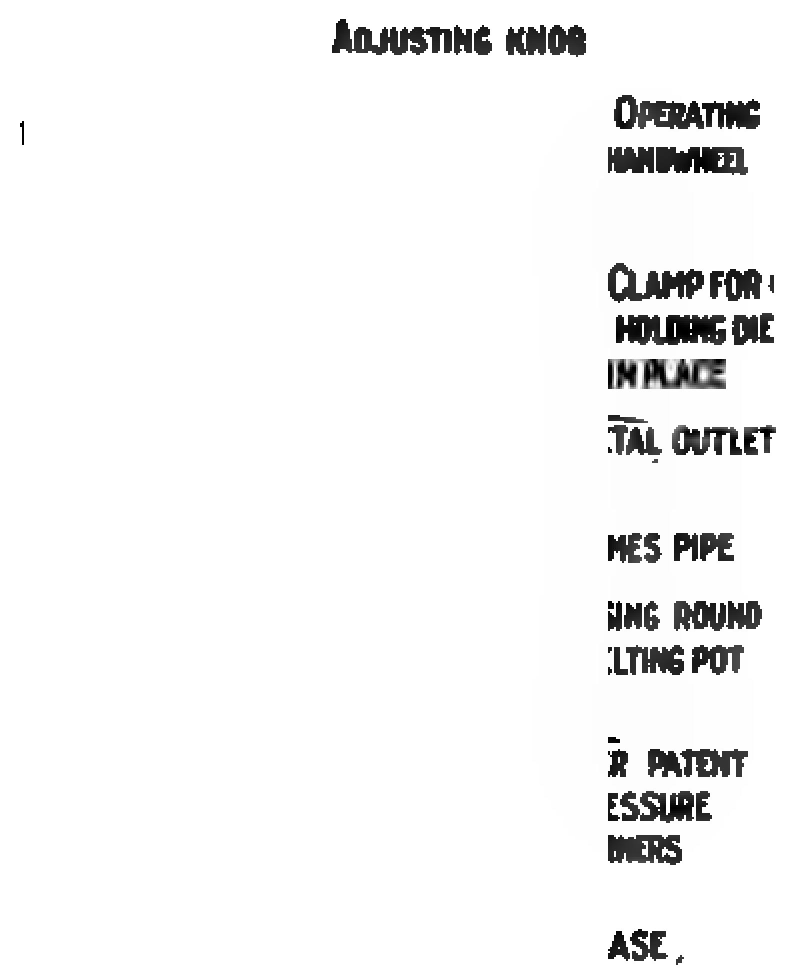



Fig. 10.—The Monometer Die-Casting Machine.

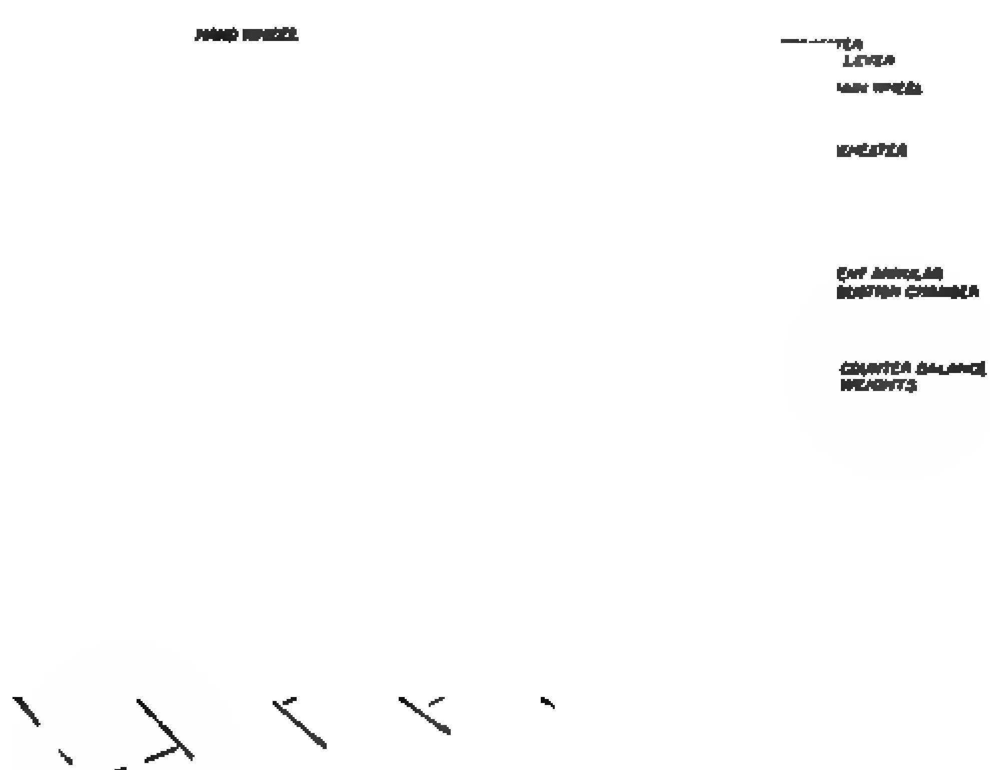


Fig. 11.—Monometer Aluminium Bar Casting Machine.

for die casting, type casting, and for white metal bearings.* Fig. 9 shows the die casting machine in outline, and Fig. 10 an outside photographic view of same.

The die casting machine is equipped with an automatic heat control,† so that the temperature may be maintained constant. The mould is held in position under a clamp, and the large hand-wheel shown in both illustrations, which works in conjunction with a rack and pinion, is employed to force the molten metal from the bottom of the melting-pot cylinder through an upwardly directed duct, to a cone seating situated immediately below a clamping device for holding the die in place.

The melting-pot is gas heated and is made of "tantulum" iron, so that it can withstand heat for long periods.

The vertical screw with the horizontal hand-wheel, shown in Figs. 9 and 10, is provided for clamping the die or metallic-mould in position over the outlet orifice through which the molten metal is forced.

The steel moulds employed must be very carefully designed, and the question of their design and construction governs the cost and production-rate of the castings; the dies themselves are the most expensive feature of the process, and it does not, as a rule, pay to die-cast a smaller number than, say, 100 of any given shape. On the other hand, the life of the dies, when proper care is taken, is exceedingly great, and several thousands of castings may be made with one set of dies.

The finish obtained in die casting work is excellent, and in the majority of cases no subsequent machining is necessary. Interchangeable parts can be readily made, and parts of a composite structure or machine will fit together as accurately as if machined.

Holes, slots, keyways, notches, teeth, internal and external screw threads, etc., can be reproduced in the die casting with almost the same accuracy as if carefully machined. Apparatus

* Made by the Monometer Manufacturing Co. These illustrations are kindly given by the *Ministry of Munitions Journal*.

† Described on p. 548, Vol. I.

made in several parts in order that it may be machined in the ordinary way can generally be combined in a single die casting, so that a cheaper and better looking article can be obtained.

Die castings are particularly suitable for quantity production work in connexion with the components of magnetos,

FIG. 12.—EXAMPLES OF DIE CASTINGS.

engine brackets, unions, electrical instruments, aircraft instruments (brackets, gears, wheels, etc.), motor instruments, automatic machine parts, levers, gas and water meters, telephones, textile machines, gramophones, taximeters, etc.

Figs 12 and 13 show some typical sets of die castings.* The casting shown in (*a*), Fig. 13, weighed 4 pounds ; (*b*) shows some tooth wheeled work cast accurately to size ; (*c*) shows an intricate taximeter housing ; and (*d*) a machine bracket.

* Examples in Fig. 12 are by the Prana Die Casting Co., and in Fig. 13 by the Doehler Die Casting Co.

It is possible, with this process, to cast in metal pins, tubes, bushes, etc., in brass, steel, or other metal, for special wearing parts.

A B

C D

FIG. 13.—EXAMPLES OF DIE CASTINGS.

## Other Metals for Die Casting Purposes.

Whilst dealing with the general subject of die casting, it may be of some interest to mention the various metals which are used for this process, in addition to aluminium.

There are five distinct classes of metal or alloys employed; each class being identified by the principal metal constituent, as follows, namely: (1) zinc, (2) tin, (3) lead, (4) aluminium, and (5) copper. The first three metals are distinguished by their low melting points and low strength and hardness values.

Alloys of zinc, tin, and lead are employed for parts not requiring much strength, such as cover-plates, pulleys, brackets and the like. Owing to the cheapness and low melting points of the metals, they are more economical to produce, as a rule.

Babbitt and tin-lead bearings, and linings for bronze bearings, are now frequently die-cast, so that little if any subsequent machinery is necessary; usually the finished bearings can be lightly scraped in.

An average zinc base alloy has a tensile strength of about 8 tons per square inch, but with little or no ductility.

It is not usual to employ aluminium alone for die castings, but to alloy it with metals such as copper, manganese, zinc, chromium, and tin, so that the resulting metal is harder and stronger. The alloys recommended* for die casting are those containing from 7 to 12 per cent. of copper, either with or without the addition of manganese. Such alloys have been found to stand the test of time very well, whilst the tensile strength is high (from 9 to 12 tons per square inch), and both the melting point and shrinkage relatively low.

The shrinkage for the above copper-aluminium alloys is about 1·2 to 1·3 per cent., being rather smaller with higher copper contents.

The following table gives the compositions† of certain alloys of copper, tin, aluminium, and zinc, suitable for casting under pressure in metal moulds, for purposes where ordinary brass castings are suitable.

* The British Aluminium Company.
† E. L. Lake, *Amer. Machinery*, 13th February, 1908.

## TABLE VI.

### Alloys for Casting Under Pressure in Metal Moulds.

| *No.* | *Tin.* | *Copper.* | *Aluminium* | *Zinc.* | *Lead.* | *Antimony.* | *Iron.* |
|---|---|---|---|---|---|---|---|
| 1 | 14·75 | 5·25 | 6·25 | 73·75 | 0 | 0 | 0 |
| 2 | 19·00 | 5·00 | 1·00 | 72·70 | 2 | 0·3 | 0 |
| 3 | 12·00 | 10·60 | 3·40 | 73·80 | 0 | 0 | 0·2 |
| 4 | 30·80 | 20·40 | 2·60 | 46·20 | 0 | 0 | 0 |

For general work, in which the properties of the ordinary brass castings are required, Nos. 1 and 2 alloys are suitable. Nos. 3 and 4 give harder and stronger castings.

Most of the alloys used for die casting may be nickel plated, bronzed, coppered, brassed, polished, or finished in any desired manner, very effectively.

The latest step in die casting work has been to employ *copper base* alloys, such as *aluminium bronze*, which have a higher melting point and much higher tensile strengths and elongations. The alloys which have been* successfully employed include brass, containing (60 copper to 40 zinc), with the addition of about 2 per cent. of aluminium, manganese bronze, and aluminium containing iron.† The aluminium is added to give fluidity to the metal and better definitions to the castings. The manganese-bronze used contained less than 1 per cent. of manganese with a little iron and aluminium.

The chief objection to these metals is that the surface of the die quickly becomes covered with a coating of zinc oxide which requires brushing off after each cast. The best results are stated to have been obtained with aluminium bronze containing iron, and commercial die castings are now produced

* "Die Casting." The Use of Aluminium Bronze, H. Rix and H. Whitaker, *Journ. Inst. of Metals*, 1918.

† Also see "Pressure Method of Casting Copper Alloys, p. 110.

in alloys containing from 7 to 10 per cent. of aluminium and 1 to 4 per cent. of iron.

The average results obtained from 24 test bars cast 1 inch chill and cooled in air, were as follows—

| | |
|---|---|
| Yield Point | 14·7 tons per square inch |
| Tensile Strength | 35·5 ,, ,, ,, |
| Elongation in 2 inches | 24 per cent. |
| Reduction of Area | 21·8 ,, |

The variable results obtained with the same metal under the ordinary casting conditions are accounted for by the fact that the mechanical properties of the copper-aluminium-iron alloys vary considerably with heat treatment, so that accurate pyrometric control is necessary for consistent results.

The temperature of the molten metal and of the die should be known, and the rate of cooling of the casting definitely fixed.

The material which was found the most satisfactory for making the dies was a close-grained cast iron, as hard as is consistent with good machining properties; the block of iron for the dies should be chill-cast.

It is also possible, in many cases, to cast the dies almost to their finished shape before machining.

Each alloy used for die casting requires its own particular design of die, as regards gating, ventilating, and shrinkage.

The number of castings obtainable with cast iron dies as described above vary from 5000 to 7000 before the dies show any signs of deterioration.

No facing or special treatment is necessary, nor does the die require to be cooled down every few minutes; but the plugs, which are made of steel, are dipped in a graphite wash between each cast to preserve their shape, and even then they do not last as long as the die.

### Air Ministry Specification for Soft Aluminium Sheets. (Extract.)

*Specific Gravity* 2·75.

1. Quality and Manufacture.—The sheets are to be made of aluminium assaying not less than 98 per cent.

They are to have bright, clean, and smooth surfaces, free from discoloration, blisters, lamination, or surface defects of any kind, and are to be quite fair and free from buckle.

2. ACCURACY OF DIMENSIONS.—The sheets are to be made of the sizes and gauges stated on the order. The thickness is not to differ from the thickness specified by more than the following tolerances—

| *Thickness of Sheets.* | | *Tolerances* |
|---|---|---|
| *Gauge.* | *Inch.* | *Inch.* |
| 10 | ·128 and thicker | ± ·008 |
| 14 | ·080 " " | ± ·006 |
| 19 | ·040 " " | ± ·004 |
| 23 | ·024 " " | ± ·003 |
| Thinner | | ± ·002 |

3. MECHANICAL TESTS.—The sheets are to comply with the following tests—

*Tensile Tests.*—Strips 12 inches long × 1¾ inches wide cut longitudinally from any portion of the sheet are to give results not less than the following. The effective part of the test piece is to be 4 inches long × 1¼ inches wide—

| | |
|---|---|
| Ultimate strength | 5¼ tons per square inch. |
| Elongation in 4 inches | 15 per cent. |

*Bending Tests.*—Strips cut longitudinally or transversely are to stand bending double and closing tight down without cracking.

## AIR MINISTRY SPECIFICATION FOR HALF-HARD ALUMINIUM SHEETS. (Extract.)

### *Specific Gravity* 2·75.

1. QUALITY AND MANUFACTURE.—The sheets are to be made of aluminium assaying not less than 98 per cent.

They are to have bright, clean, and smooth surfaces, free from discoloration, blisters, lamination, or surface defects of any kind, and are to be quite fair and free from buckle.

2. ACCURACY OF DIMENSIONS.—The sheets are to be made of the sizes and gauges stated on the order. The thickness is not to differ from the thickness specified by more than the following tolerances—

| *Thickness of Sheets.* | | *Tolerances.* |
|---|---|---|
| *Gauge.* | *Inch.* | *Inch.* |
| 10 | ·128 and thicker | ± ·008 |
| 14 | ·080 " " | ± ·006 |
| 19 | ·040 " " | ± ·004 |
| 23 | ·024 " " | ± ·003 |
| Thinner | | ± ·002 |

3. MECHANICAL TESTS.—The sheets are to comply with the following tests—

*Tensile Tests.*—Strips 12 inches long × 1¾ inches wide cut longitudinally from any portion of the sheet are to give results not less than the following. The effective part of the test piece is to be 4 inches long × 1¼ inches wide—

| | |
|---|---|
| Ultimate strength | 7·5 tons per square inch. |
| Elongation in 4 inches | 10·0 per cent. |

*Bending Tests.*—Strips cut longitudinally or transversely are to stand bending double over a radius equal to the thickness of the strip without cracking.

## AIR MINISTRY SPECIFICATION FOR ALUMINIUM SHEETS. (Extract.)

*Specific Gravity* 2·75

1. QUALITY AND MANUFACTURE.—The sheets are to be made of aluminium assaying not less than 98 per cent.

They are to have bright, clean, and smooth surfaces, free from discoloration, blisters, lamination, or surface defects of any kind, and are to be quite fair and free from buckle.

2. ACCURACY OF DIMENSIONS.—The sheets are to be made of the sizes and gauges stated on the order. The thickness is not to differ from the thickness specified by more than the following tolerances—

| | |
|---|---|
| For sheet of 23 S.W.G. and thinner .. .. | ± ·001 |
| „ „ 19–22 S.W.G. .. .. .. | ± ·002 |
| „ „ 14–18 „ .. .. .. | ± ·004 |
| „ „ 6–13 „ .. .. .. | ± ·006 |

3. MECHANICAL TESTS.—The sheets are to comply with the following tests—

*Tensile Tests.*—Strips 12 inches long × 1½ inches wide cut longitudinally from any portion of the sheet are to give results not less than the following. The effective part of the test piece is to be 4 inches long × 1½ inches wide—

| | |
|---|---|
| Ultimate strength .. .. .. | 10 tons per square inch. |
| Elongation in 4 inches .. .. | 3 per cent. |

*Bending Tests.*—Strips cut longitudinally or transversely are to stand bending double over a radius equal to the thickness of the strip without cracking.

## ALUMINIUM ALLOYS

The name "aluminium alloys" is given to those alloys in which the principal constituent is aluminium, or in which aluminium is present in the greater proportion.

These alloys include aluminium alloyed with elements such as copper, magnesium, manganese, zinc, tin, iron, silicon, antimony, chromium, vanadium, and tungsten; and the various commercial alloys are usually known by their trade names, such as Duralumin, Aeromin, Duralium, Magnalium, Vanalium, Navaltum, Wolframinium, and Romanium; the

names are sometimes indicative of the elements present, as in the case of the alloys Magnalium (magnesium), Vanalium (vanadium), and Wolframinium (Tungsten), but in many cases the compositions are a matter of trade secrecy.

Invariably the alloys are harder, stronger, and more ductile than the pure metal itself, and in some cases they possess better corrosion-resisting qualities.

## International Aircraft Standard Specifications.*

### 3N16—*Specifications for Aluminium Alloy Sheet.*

1. General.—The general specifications, 1G1, shall form, according to their applicability, a part of these specifications.

2. Material.—The aluminium alloy of these sheets shall be made from standard No. 1 aluminium conforming to I.A.S.B. specification 2N1. The specific gravity of the aluminium alloy shall not be greater than 2·85.

3. Manufacture.—No scrap shall be used other than that produced in the manufacturer's own plants and which is of the same composition as the material specified.

4. Workmanship and Finish.—(*a*) All sheets shall be sound, flat, free from buckles, seams, discoloration, or other surface defects.

(*b*) Any sheet may be rejected because of injurious defects or faults in manufacture at any time, notwithstanding that it has previously passed inspection; it shall be returned to the manufacturer at the latter's expense. This clause shall not be taken to apply to materials fabricated after export.

5. Physical Properties and Tests.—The sheets may be specified in either of two tempers as desired. Specimens cut in any direction from the sheets must have the following physical properties—

*Tensile Test.*—(*a*)

| | Temper 1. | | Temper 2. | |
|---|---|---|---|---|
| | *Pounds. per square inch.* | *Kilograms per square millimetre.* | *Pounds per square inch.* | *Kilograms per square millimetre.* |
| Minimum tensile strength .. .. | 55000 | 38·6 | 50000 | 35·1 |
| Minimum yield point .. .. | 25000 | 17·5 | 25000 | 17·5 |
| Minimum elongation in 2 inches .. | 15 per | cent. | 20 per | cent. |

*Bend Test.*—(*b*) Strips cut from sheets of either temper shall withstand being bent cold through an angle of 180° around a diameter equal to four times the thickness of the sheet.

* Other Official Specifications are given at the end of this Section.

6. Selection of Test Specimens.—Test specimens shall be cut from a sheet selected from each 500 pounds or individual lot submitted of less than 500 pounds.

7. Dimensions and Tolerances.—The tolerances upon sheets shall be those given in the table below—

| *Brown & Sharp Gauge.* | *Thickness. Inch.* | *Tolerance. Inch.* | *Thickness. Millimetres.* | *Tolerance. Millimetre.* |
|---|---|---|---|---|
| 10–17 | 0·1019–0·0453 | ± 0·003 | 2·588–1·151 | 0·070 |
| 18–26 | ·0403– ·0159 | ± ·002 | 1·024– ·404 | ·051 |

8. Delivery, Shipping, and Packing.—The sheets shall be delivered in boxes of gross weight not greater than 220 pounds (100 kilogrammes).

## 3N11—*Specifications for Aluminium Alloy Castings.*

1. General.—The general specifications, 1G1, shall form, according to their applicability, a part of these specifications.

2. Use.—Two alloys are described.

Alloy 1 is suitable for crank cases and general purposes for which tensile strength is required.

Alloy 2 is suitable for die castings for bearing surfaces and pistons for use at higher temperatures.

3. Material.—(*a*) These alloys shall have the following compositions

| | *Alloy No.* 1. | *Alloy No.* 2. |
|---|---|---|
| Specific gravity .. | 2·89 | 2·95 |
| Copper .. .. | 7·0–8·5 per cent. | 9·25–10·75 per cent. |
| Impurities .. .. | Not over 1·7 per cent. | Not over 1·7 per cent. |
| Aluminium .. .. | Balance | Balance |

(*b*) Ingot aluminium of grades Standard No. 1 and Standard No. 2 may be used in making these alloys.

4. Workmanship and Finish.—(*a*) The castings are to be clean, sound, and free from blowholes, misruns, cracks, shrinks, and similar defects.

(*b*) No repairing, plugging, or welding will be allowed unless previous permission in writing has been obtained from the inspector; such permission will only be given when the defects to be repaired are small and do not affect the strength of the casting.

5. PHYSICAL PROPERTIES AND TESTS.—(*a*) The alloys shall have the following minimum physical properties—

*Tensile Test*—

| | *Alloy No. 1, Sand cast.* | *Alloy No. 2, Sand or Die cast.* |
|---|---|---|
| Tensile Strength .. | 18,000 pounds per square inch (12·65 kg./mm.$^2$) | 18,000 pounds per square inch (12·65 kg./mm.$^2$) |
| Elongation in 2 inches (50·8 mm.) .. .. | 1·5 per cent. | — |

(*b*) These alloys when poured hot into very thin difficult sections, such as crank-case pans, carburettors, and manifolds, shall not be required to show a greater tensile strength than 14,000 pounds per square inch (9·84 kg./mm.$^2$).

6. SELECTION OF TEST SPECIMENS.—(*a*) At least one sample is to be cast to represent each crank-case or other large casting; this is to be attached to the casting; no chills may be applied to the test specimen.

(*b*) The number of test samples for smaller castings is left to the discretion of the inspector, who is to satisfy himself that the quality of the metal used is satisfactory and uniform.

(*c*) The latter samples are to be cast separate, but also in sand and without the use of chills.

7. DIMENSIONS AND TOLERANCES.—(*a*) the castings are to be accurately in accordance with the drawings, and sufficient allowance is to be made to enable them to be machined where required to the finished dimensions without leaving evidence of the cast surface.

(*b*) A tolerance of 3 per cent. is allowed in the weight of the individual castings.

## Strength of Aluminium Alloys.

Some of the general properties of these alloys have been systematically investigated, so that for any given elements the effect of varying proportions upon the strength is known. The strength properties of certain of the better known commercial alloys will be considered under their own headings, and the present considerations will therefore be confined to the more general cases of aluminium alloy series.

It may, however, be mentioned that it is now possible to obtain alloy castings in strengths up to 18 tons per square inch (in the chill cast state), with from 3 to 5 per cent. elongation, and rolled sheet, bars, tubes, and sections in tensile strengths varying from 20 to 40 tons per square inch, with corresponding elongations of from 23 to 3 per cent.

The hardnesses vary from 50 to 180 on the Brinell scale.

**Comparisons Between Aluminium Alloys.**

The suitability of any alloy for aeronautical, and to a lesser extent for automobile work, will depend upon its tensile strength, ductility, and weight, other conditions remaining the same. The most suitable alloy will then be that which gives the greatest strength, combined with a certain minimum permissible ductility, with the least weight.

The term " specific tenacity " has been employed to denote the ratio of the tensile strength in tons per square inch, divided by the weight of a cubic inch in pounds ; the highest specific tenacity value will therefore correspond to the most suitable material as above defined.

The following are typical specific tenacity values for different aluminium alloys, together with those for a few other aeronautical materials for comparison purposes—

### TABLE VII.

SPECIFIC TENACITY VALUES FOR ALUMINIUM ALLOYS, ETC.

(For ductilities of not less than 16 per cent. in 2 inches.)

| *Material.* | *Condition.* | *Specific Tenacity.* |
|---|---|---|
| Mild Steel .. .. .. | As Rolled | 108 |
| Nickel-Chrome Steel .. | Air Hardened | 420 |
| Silver Spruce .. .. | Along Grain | 250 |
| Duralumin .. .. .. | From an Airship | 270 |
| Aluminium-Zinc No. 15 .. | Hot Rolled ½ in. Bar | 166 |
| Aluminium-Zinc-Magnesium 15M. .. .. .. | " " ¾ " | 234 |
| Aluminium-Zinc No. 20 .. | " " 1¼ " | 203 |
| Aluminium-Zinc-Magnesium 20M. .. .. .. | " " ¾ " | 229 |
| Aluminium-Copper-Zinc— | | |
| No. 15/3 .. .. | " " 1¼ " | 212 |
| No. 20/3 .. .. | " " ½ " | 245 |
| No. 25/3 .. .. | " " ⅞ " | 263 |
| Duralumin .. .. .. | ⅞ inch Rolled Bar | 297 |
| Pure Aluminium .. .. | Rolled Bar | 94 |
| Alumin-Copper-Nickel (Cu. 2·1, Ni. 5·33) .. | Cold Drawn* | 162 |

* 7·5 per cent. elongation.

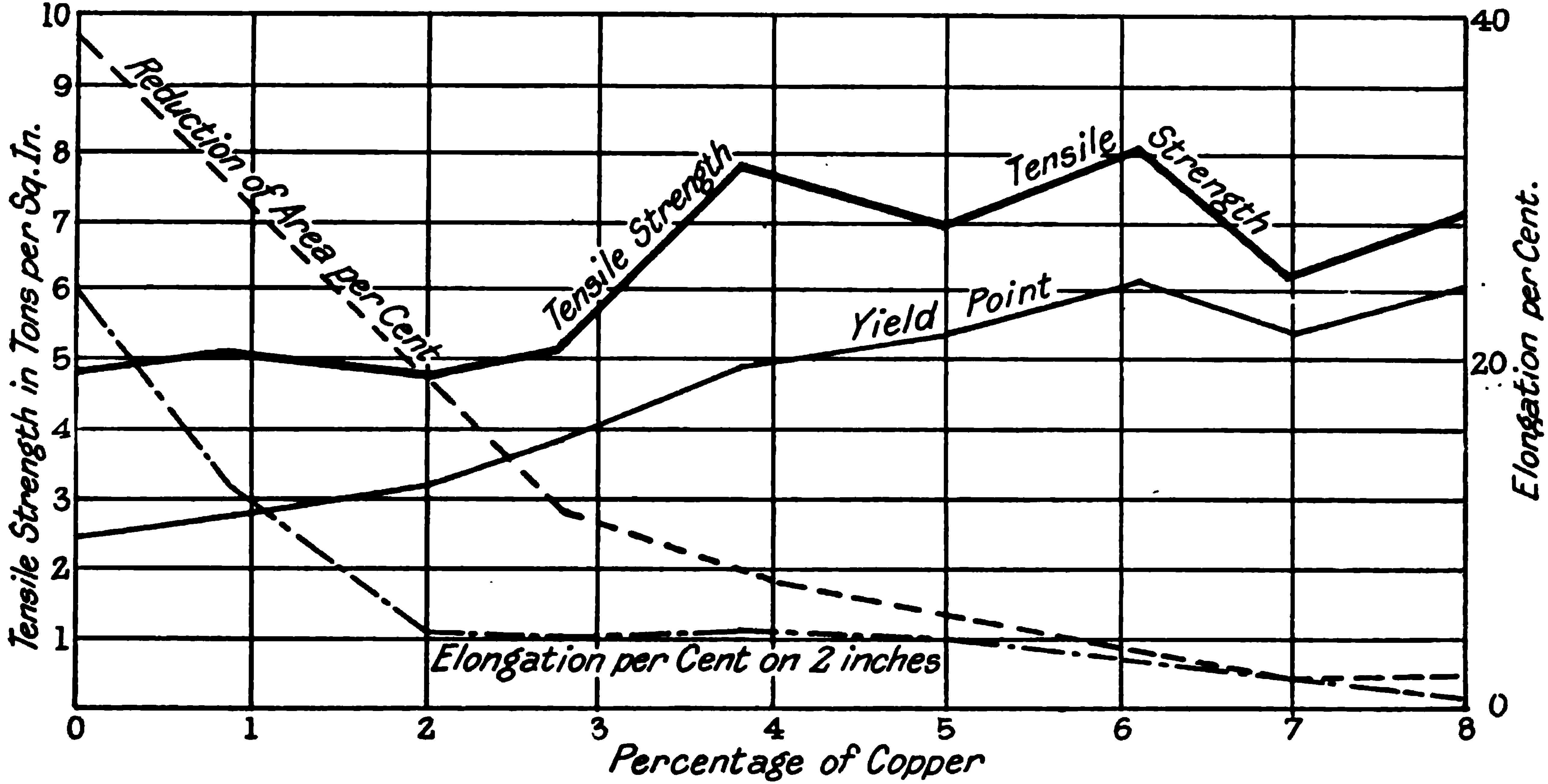



FIG. 14.—SHOWING THE EFFECT OF COPPER ON THE MECHANICAL PROPERTIES OF ALUMINIUM SAND CASTINGS.

## TABLE VIII.

### Properties of Aluminium-Copper Alloys. (Unwin.)

| *Composition.* Aluminium | *Composition.* Copper. | *Modulus of Elasticity (tons per sq. inch).* | *Tensile Strength (tons per sq. inch).* | *Elongation per cent.* | *Remarks.* |
|---|---|---|---|---|---|
| 93 | 7 | 5700 | 8·10 | 1·1 in 11 ins. | Cast Condition |
| 93 | 7 | 4050 | 5·20 | 0·6 ,, ,, | ,, ,, |
| 93 | 7 | 4100 | 5·90 | 0·6 ,, ,, | ,, ,, |
| 93 | 7 | 4450 | 7·70 | 0·6 ,, ,, | ,, ,, |
| 94 | 6 | 4196 | 6·26 | 1·2 in 8 ins. | ,, ,, |
| 93 | 7 | 4950 | 8·30 | 1·7 ,, ,, | ,, ,, |
| 96 | 4 | 4670 | 10·30 | 3·6 ,, ,, | Rolled ,, |
| 96·5 | 2 | 4400 | 11·70 | 1·3 ,, ,, | With 1·5 per ct. of Chromium. |

*Note.*—The first four results are by the Institute of Technology, Boston, the fifth by Unwin, and the last three by Prof. Carpenter.

## TABLE IX.

### Properties of Aluminium-Zinc Alloys.

(Rosenhain and Archbutt.)

| *Percentage of Zinc.* | *Condition.* | *Yield Point (tons per sq. inch).* | *Tensile Strength (tons per sq. inch).* | *Elongation per cent. on 2 inches.* |
|---|---|---|---|---|
| 5 | Sand Cast .. .. | 2·70 | 5·20 | 16·0 |
| | Chill Cast .. .. | 2·80 | 6·60 | 29·0 |
| | Hot rolled Bars 1¼ins. | 4·30 | 7·48 | 33·0 |
| 11 | Sand Cast .. .. | 6·40 | 9·41 | 8·0 |
| | Chill Cast .. .. | 5·00 | 10·24 | 16·0 |
| | Hot rolled Bars ½ in. | 9·42 | 13·78 | 33·0* |
| 15 | Sand Cast .. .. | 9·60 | 11·14 | 2·0 |
| | Chill Cast .. .. | 5·80 | 11·69 | 8·5 |
| | Hot rolled Bars ½ in. | 11·61 | 17·92 | 31·0* |
| 20 | Sand Cast .. .. | 10·00 | 13·07 | 0·7 |
| | Chill Cast .. .. | 7·80 | 13·87 | 4·0 |
| | Hot rolled Bars 1¼ ins. | 17·30 | 22·64 | 20·5 |
| 25 | Sand Cast .. .. | Nil. | 16·26 | 1·0 |
| | Chill Cast .. .. | 9·10 | 13·50 | 3·5 |
| | Hot rolled Bars ½ in. | 20·24 | 24·03 | 27·0* |
| | Hot rolled Bars 1¼ ins | 25·00 | 27·09 | 16·5 |
| 30 | Sand Cast .. .. | 11·70 | 16·63 | 1·5 |
| | Chill Cast .. .. | 10·30 | 17·92 | 3·0 |

* Extension on 1 inch.

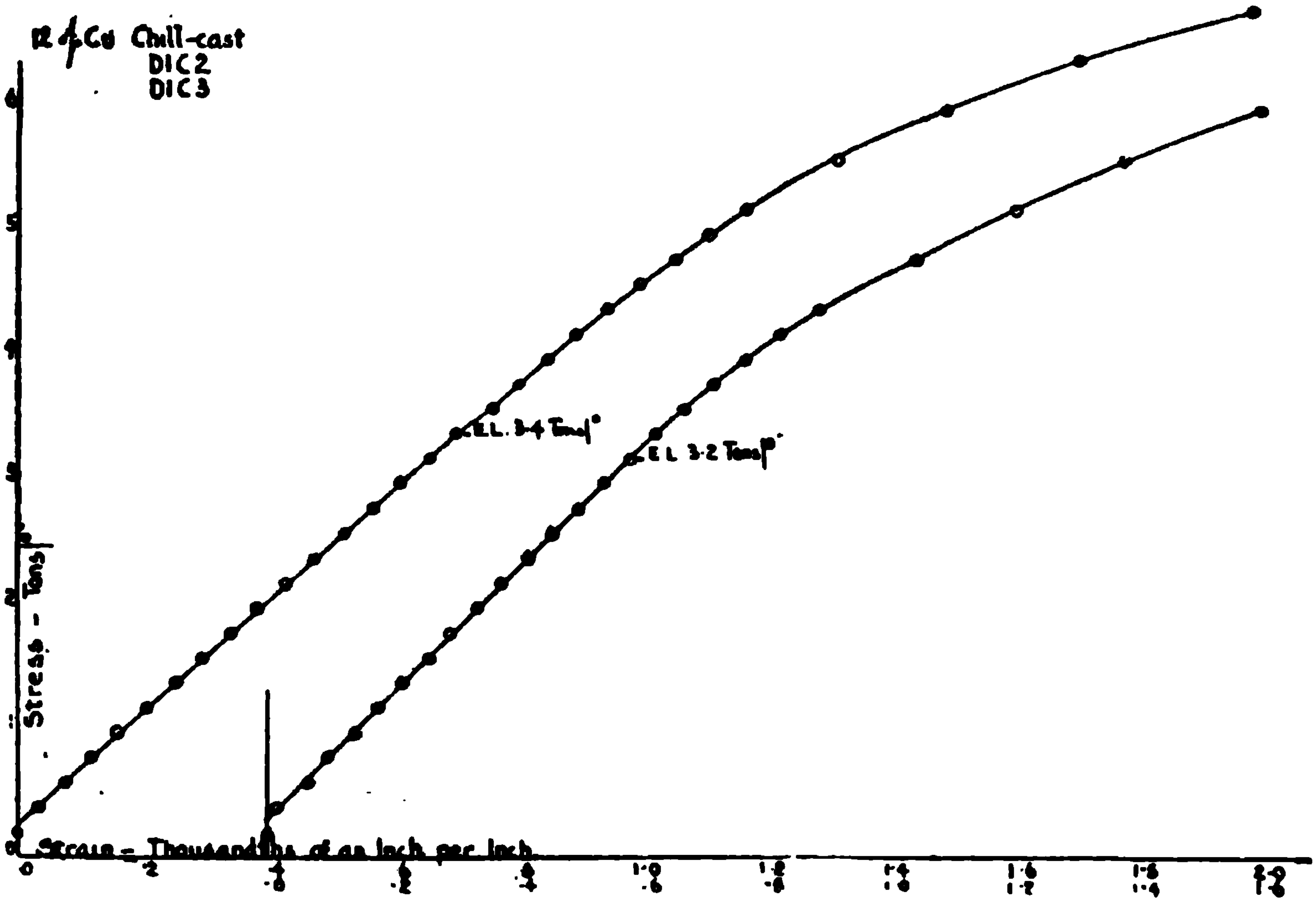



Fig. 15.—Showing the Properties of 12% Copper-Aluminium Chill Castings.

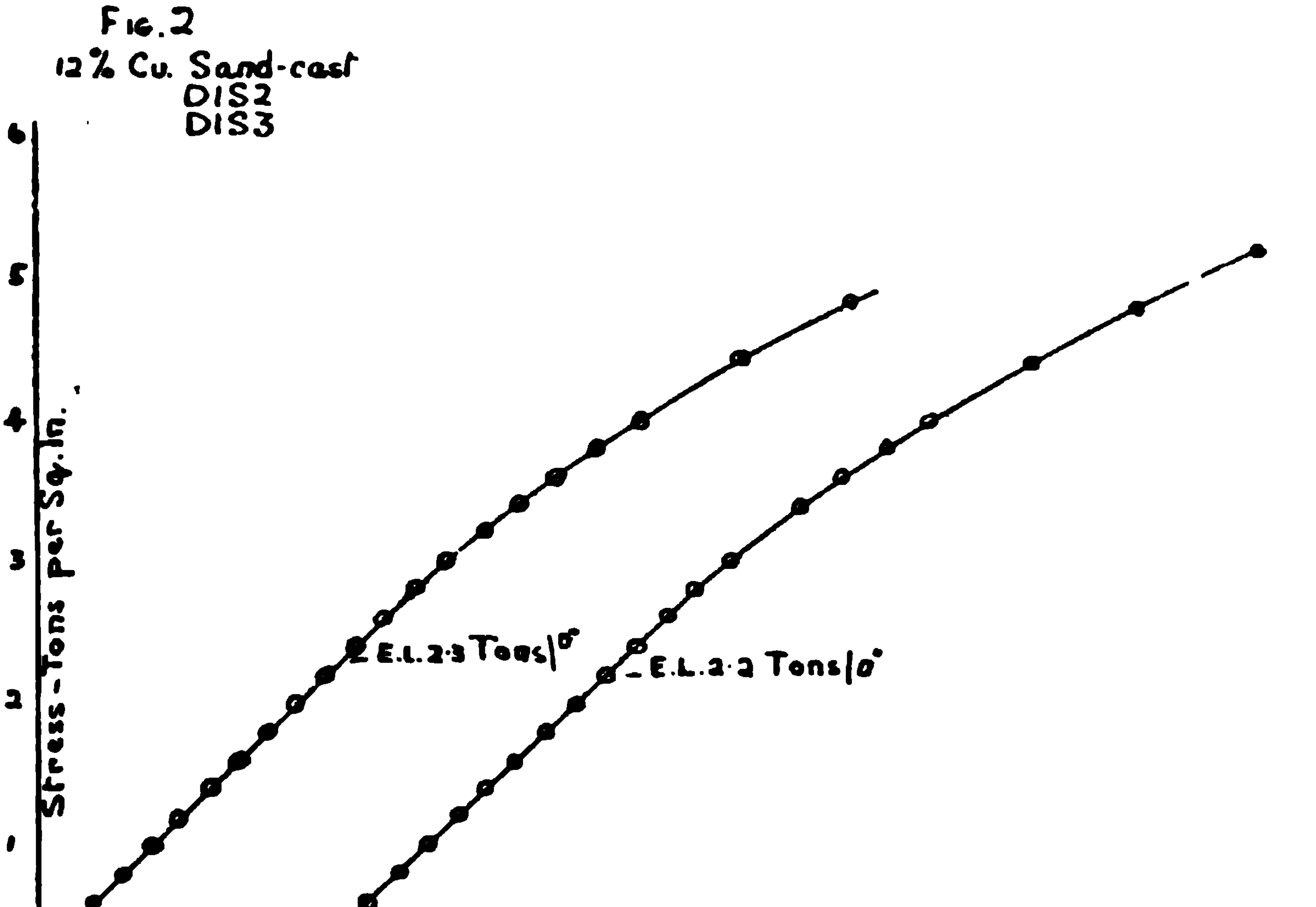



Fig. 16.—Showing the Properties of 12% Copper-Aluminium Sand Castings.

*Note.*—The alloys given in Table IX vary in specific gravity from 2·7 to 3·3 as their zinc content increases up to 30 per cent. (the limiting value). These alloys are all forgeable at temperatures between 300° C. and 400° C., and can be cast into plain shapes, but are not recommended for intricate shapes.

FIG. 17.—ALUMINIUM ALLOY CONTAINING 2% COPPER, 3% SILICON, AND 0.3% IRON (SAND-CAST). $CuAl_2$ IS SHOWN BLACK, $FeAl_3$ AS WHITE NEEDLES. SILICON AS HALF-TONE. ALUMINIUM BACKGROUND. MAGNIFIED 500 TIMES.

## TABLE X.

### PROPERTIES OF ALUMINIUM-COPPER-TIN ALLOYS.

(Carpenter.)

| *Compositions (per cent).* | | | *Specific Gravity.* | *Tensile strength (tons per sq. inch).* | *Elongation per cent. in 6 inches.* |
|---|---|---|---|---|---|
| *Aluminium.* | *Copper.* | *Tin.* | | | |
| 85 | 7·5 | 7·5 | 3·02 | 13·4 | 4·0 |
| 6·25 | 87·5 | 6·25 | 7·35 | 28·2 | 3·8 |
| 5 | 5 | 90 | 6·82 | 4·9 | 10·1 |

*Note* 1.—The above are the maximum strengths for alloy-series in which two of the three metals are in equal proportions.

*Note* 2.—Aluminium is strengthened by the addition of equal parts of copper and tin up to 7·5 per cent. of each, beyond which the strength decreases.

**Aluminium-Zinc Alloys.**

A full description of the results of a long series of researches upon the properties of aluminium-zinc alloys and on some of their derivatives obtained by the addition of copper and other metals is given in the Tenth Report to the Alloys Research Committee of the Institution of Mechanical Engineers, to which the reader is referred. The following results refer to the most promising members of the series of binary alloys of aluminium and zinc. These alloys can be rolled hot without any difficulty, and can be produced in any desired shape or size.

TABLE XI.

COMPOSITIONS AND SPECIFIC GRAVITIES OF ALUMINIUM-ZINC ALLOYS.*

| *Designation.* | *Composition.* | | *Specific Gravity.* |
|---|---|---|---|
| | *Aluminium.* | *Zinc.* | |
| Alloy No. 15 .. | 85 | 15 | 2·96–2·99 |
| Alloy No. 20 .. | 80 | 20 | 3·06–3·09 |
| Alloy No. 26 .. | 74 | 26 | 3·18–3·24 |

The following are a few typical test results for these alloys—

TABLE XII.

STRENGTH PROPERTIES OF ALUMINIUM-ZINC ALLOYS

| *Alloy.* | *Condition.* | *Yield Point (tons per sq. inch)* | *Tensile Strength (tons per sq. inch).* | *Elongation on 2 inches per cent.* | *Reduction of Area, per cent.* |
|---|---|---|---|---|---|
| No. 15 | Sand casting .. .. .. | 9·55 | 11·14 | 2 | — |
| | Sand casting annealed at 400°C | 5·87 | 10·0 | 3·5 | — |
| | Chill casting .. .. | 5·80 | 11·7 | 8·5 | — |
| | Chill casting annealed at 400°C | 4·56 | 10·90 | 10 | — |
| | Rolled bars, ½ inch to 1¼ inch | 6·8–11·6 | 16·4–17·9 | 33–30 | 58·5–53·4 |
| | Rolled bars annealed at 400°C. | 4·7–7·4 | 13·6–15·3 | 36–31 | 60·4–49·5 |
| | Wire, 0·1285 inch annealed at 400° C. .. .. .. | 15·33 | 19·27 | 16·5 | — |
| | Sheet, ·07 inch transverse* .. | 14·21 | 21·01 | 6·5 | — |
| | „ ·07 „ longitudinal | 14·38 | 21·76 | 1·5 | — |
| | „ ·13 „ transverse .. | 12·05 | 15·58 | 5 | — |
| | „ ·13 „ longitudinal | 13·17 | 17·98 | 12·8 | — |

* See also p. 39.

TABLE XII.—*continued.*

| | | | | | |
|---|---|---|---|---|---|
| No. 20 | Sand casting .. .. .. | 10·04 | 13·07 | 1 | — |
| | " " annealed at 400°C· | 10·55 | 13·27 | 2 | — |
| | Chill casting .. .. .. | 7·84 | 13·82 | 4 | — |
| | " " annealed at 400°C | 7·56 | 12·95 | 2 | — |
| | 1¼ inch rolled bar .. .. | 17·3 | 22·64 | 20·5 | 36·3 |
| | ⅜ " " " .. .. | 12·41 | 21·40 | 25·5 | 45·8 |
| | ⅜ " " " annealed at 400° C. .. .. | 11·81 | 18·7 | 22 | 27·5 |
| | Sheet ·07 inch transverse .. | 12·93 | 23·60 | 1·5 | — |
| | " ·07 " longitudinal .. | 12·76 | 22·69 | 0·5 | — |
| | " ·07 " annealed .. | 11·87 | 17·25 | 6 | — |
| | " ·13 " transverse .. | 12·08 | 12·41 | — | — |
| | " ·13 " longitudinal .. | 11·85 | 22·08 | — | — |
| | " ·13 " annealed (transverse) | 13·32 | 14·90 | 15·5 | — |
| No. 26 | Sand casting .. .. .. | 11·22 | 17·33 | 2·5 | — |
| | Chill casting .. .. .. | 10·6 | 17·72 | 4 | — |
| | 1¼ inch rolled bar .. .. | 25 | 27·09 | 16·5 | 27·5 |
| | ⅜ " " " .. .. | 20·2 | 23·86 | 20·5 | 40·5 |
| | 1³⁄₁₆ " bar drawn with annealing | 22·3 | 24·9 | 11·5 | 13·30 |

*Note.*—Other values are given in Table IX.

## Aluminium-Copper-Zinc Alloys.

The following are the compositions and specific gravities of some interesting alloys of this series, which have possessed certain strength and ductility properties rendering them particularly applicable to commercial purposes.

TABLE XIII.

COMPOSITION AND SPECIFIC GRAVITIES OF ALUMINIUM-COPPER-ZINC ALLOYS.

| *Designation.* | *Composition per cent.* | | | *Specific Gravity.* |
|---|---|---|---|---|
| | *Aluminium* | *Copper.* | *Zinc.* | |
| Alloy 15/3 .. | 82 | 3 | 15 | 2·91–3·10 |
| Alloy 20/3 .. | 77 | 3 | 20 | 3·11–3·30 |
| Alloy 25/3 .. | 72 | 3 | 25 | 3·23–3·26 |

In connexion with the first two alloys, namely, Alloys 15/3 and 20/3, these can be rolled fairly easily, but the rolling of Alloy 25/3, although quite possible, requires considerable care and accurate temperature control. When once broken down from the original billet, the subsequent rolling is, however, quite simple.

The following are the mechanical properties of these alloys—

## TABLE XIV.

### Strength Properties of Aluminium-Copper-Zinc Alloys.

| *Alloy.* | *Condition.* | *Yield Point in tons per sq. inch.* | *Tensile Strength in tons per sq. inch.* | *Elongation in 2 inches per cent.* | *Reduction of Area, per cent.* |
|---|---|---|---|---|---|
| No. 15/3 | Sand casting .. .. .. | 9·7 | 14·15 | 3 | — |
| | Chill casting .. .. .. | 7·4 | 14·91 | 6·5 | — |
| | 1¼ inch hot rolled bar .. | 14·73 | 23·67 | 21 | — |
| | ⅞ ,, ,, ,, ,, .. | 13·55 | 21·54 | 22 | — |
| | ⅜ ,, cold drawn bar .. | 19·60 | 24·90 | 11 | — |
| No. 20/3 | Sand casting .. .. .. | 10·92 | 15·55 | 2·5 | — |
| | Chill casting .. .. .. | 5·02 | 14·02 | 2 | — |
| | ⅞ inch hot rolled .. .. | 18·11 | 27·04 | 20 | — |
| | ⅝ ,, ,, ,, .. .. | 19·84 | 27·62 | 26 (on 1 inch) | — |
| | ·185 inch diameter wire .. | 32·83 | 34·06 | 7·5 | — |
| No. 25/3 | Sand casting .. .. | 5·71 | 18·25 | 2 | — |
| | Sand casting annealed at 400°C | 15·31 | 17·25 | 2 | — |
| | Chill casting .. .. | 5·63 | 20·22 | 3·5 | — |
| | 1¼ inch hot rolled bar .. | 22·09 | 27·92 | 4 | 8·3 |
| | 1 ,, ,, ,, ,, .. | 22·09 | 30·83 | 16·5 | 24·5 |
| | ⅞ ,, ,, ,, ,, .. | 21·76 | 30·91 | 16·75 | 27·4 |
| | ⅞ inch hot rolled bar heated to 500° C. and slowly cooled .. | 14·76 | 27·92 | 22 | 21·4 |
| | ⅝ inch hot rolled bar .. .. | 27·17 | 31·70 | 21 (on 1 inch) | 38·47 |
| | ⅝ inch hot rolled bar annealed | 18·61 | 24·40 | 24 (on 1 inch) | 42·41 |
| | Sheet 0·156 inch longitudinal | 20·95 | 27·96 | 6 | — |
| | ,, 0·156 ,, transverse.. | None noticed | 24·27 | 1 | — |
| | ,, 0·156 ,, annealed .. | 18·30 | 20·51 | 4 | — |
| | ,, 0·075 ,, longitudinal | None noticed | 23·90 | 1 | — |
| | ,, 0·075 ,, transverse.. | None noticed | 26·52 | 1 | — |
| | ,, 0·075 ,, annealed .. | 14·18 | 22·30 | 4 | — |

## TABLE XV.

### Properties of Aluminium-Copper-Zinc Alloys.

| *Compositions (per cent.)* | | | *Yield Point (tons per sq. inch).* | *Tensile Strength (tons per sq. inch).* | *Elongation per cent.* |
|---|---|---|---|---|---|
| *Copper.* | *Aluminium* | *Zinc.* | | | |
| 1 | 80 | 19 | 9·5 | 14·9 | 5·5 |
| 2 | 79 | 19 | 12·5 | 16·5 | 5·7 |
| 2 | 78 | 20 | 10·4 | 14·0 | 3·3 |
| 3 | 77 | 20 | 11·5 | 16·8 | 4·5 |
| 4 | 76 | 20 | 10·4 | 15·3 | 3·8 |

*Note* 1.—The above results refer to metals in the chill-cast state.

**Aluminium-Zinc-Magnesium Alloys.**

The effect of adding small quantities of magnesium to aluminium-zinc alloys is to considerably improve the strength and hardness, but the metal is a little more difficult to work.

The following results refer to the aluminium-zinc alloys Nos. 15 and 20, referred to in Tables XI and XII, but to which 0·5 and 0·25 per cent of magnesium have been added. The beneficial effects upon the strength properties will be apparent from an examination of these tables and the following results—

TABLE XVI.

COMPOSITION AND SPECIFIC GRAVITY OF ALUMINIUM-ZINC-MAGNESIUM ALLOYS.

| *Designation.* | *Composition (Parts).* | | | *Specific Gravity.* |
|---|---|---|---|---|
| | *Aluminium* | *Zinc.* | *Magnesium.* | |
| Alloy No. 15/M5 | 85 | 15 | 0·5 | 2·99 |
| Alloy No. 20/M5 | 80 | 20 | 0·25 | 3·09 |

TABLE XVII.

STRENGTH PROPERTIES OF ALUMINIUM-ZINC-MAGNESIUM ALLOYS.

| *Alloy.* | *Condition.* | *Yield Point (tons per sq. inch).* | *Tensile Strength (tons per sq. inch).* | *Elongation in 2 inches per cent.* |
|---|---|---|---|---|
| 15/M5 | As Rolled .. .. .. | 19·9 | 28·3 | 21 |
| | Quenched from 500° C. and tested at once .. .. | 12·4 | 20·2 | 29 |
| | Ditto after 3 days .. .. | 14·8 | 22·6 | 28 |
| 20/M5 | As Rolled .. .. .. | 21·3 | 25·6 | 20 |
| | Quenched from 500° C. and tested at once .. .. | 15·4 | 23·0 | 29 |
| | Ditto after 3 days .. .. | 18·9 | 25·3 | 18·5 |

The gradual hardening effect after annealing or quenching in this group of alloys is a characteristic feature; the same effect is also noticeable in the case of Duralumin.*

**Aluminium-Magnesium Alloy.**

The following is the analysis† of a commercial aluminium-magnesium alloy, taken from a casting; the density of which was about 2·6—

| | *Per cent.* |
|---|---|
| Copper .. .. .. .. | 0·03 |
| Silicon .. .. .. .. | 0·35 |
| Zinc .. .. .. .. .. | 0·31 |
| Iron .. .. .. .. .. | 0·47 |
| Manganese .. .. .. .. | 0·23 |
| Magnesium .. .. .. .. | 7·82 |
| Aluminium .. .. .. .. | 90·79 |

The strength properties of this material is given in the table below—

TABLE XVIII.

PROPERTIES OF ALUMINIUM-MAGNESIUM ALLOY.

| *Condition.* | *Yield Point (tons per sq. inch.* | *Tensile Strength (tons per sq. inch).* | *Elongation in 2 inches per cent.* | *Specific Tenacity = Tensile Strength. / Weight per cu. inch.* |
|---|---|---|---|---|
| Casting .. .. | 9·75 | 10·69 | 0·5 (head off) | 114 |
| " .. .. | 9·43 | 10·54 | 1 | 114 |
| Sheet (annealed) | 3·94 | 23·36 | 25 | 204 |
| " " | 6·25 | 23·67 | 25 | 204 |
| " (hand rolled) | 7·91 | 31·88 | 3‡ | 275 |
| " " " | 9·92 | 26·25 | 0‡ | 228 |

Another test result upon a rolled bar of ⅞ inch diameter gave a specific gravity of 2·64, with a specific tenacity of 224 and an elongation of 14 per cent. upon 2 inches.

* See p. 54.

† "Report on Light Alloys," Dr. W. Rosenhain, Advisory Committee for Aeronautics, *Report No.* 91, Sept., 1913.

‡ Broke at shoulder and gave practically no elongation.

**Copper-Magnesium Alloy of Aluminium.**

The following is the analysis of an alloy of the above class, tested by Dr. Rosenhain*—

| | *Per cent.* |
|---|---|
| Silicon .. .. .. .. | 0·41 |
| Copper .. .. .. .. | 2·34 |
| Tin .. .. .. .. .. | Trace |
| Iron .. .. .. .. .. | 0·20 |
| Manganese .. .. .. .. | 0·10 |
| Magnesium .. .. .. .. | 2·50 |
| Aluminium .. .. .. .. | 94·45 |

The specific gravity is given as 3·2.

FIG. 18.—20% MAGNESIUM ALUMINIUM ALLOY. ALUMINIUM-MAGNESIUM COMPOUND SHOWN BLACK. MAGNIFIED 150 TIMES.

The following are the strength properties of the cast metal—

TABLE XIX.

STRENGTH OF COPPER-MAGNESIUM ALLOY OF ALUMINIUM.

| *Condition.* | *Yield Point (tons per sq. inch).* | *Tensile Strength (tons per sq. inch).* | *Elongation in 2 inches per cent.* | *Specific Tenacity.* |
|---|---|---|---|---|
| Casting .. | None noticed | 11·51 | 1 | — |
| Casting .. | 10·77 | 11·76 | 1 | — |

It was noticed that the fracture had a decided bluish tinge.

* See Footnote, p. 46.

**Copper-Chromium Alloy of Aluminium.**

The following is the analysis of an aluminium alloy in which copper and chromium are present, the other elements being probably impurities—

| | *Per cent.* |
|---|---|
| Copper .. .. .. .. .. | 3·78 |
| Chromium .. .. .. .. | 0·38 |
| Silicon .. .. .. .. | 0·35 |
| Iron .. .. .. .. .. | 0·40 |
| Manganese .. .. .. .. | 0·02 |
| Aluminium .. .. .. .. | 95·05 |

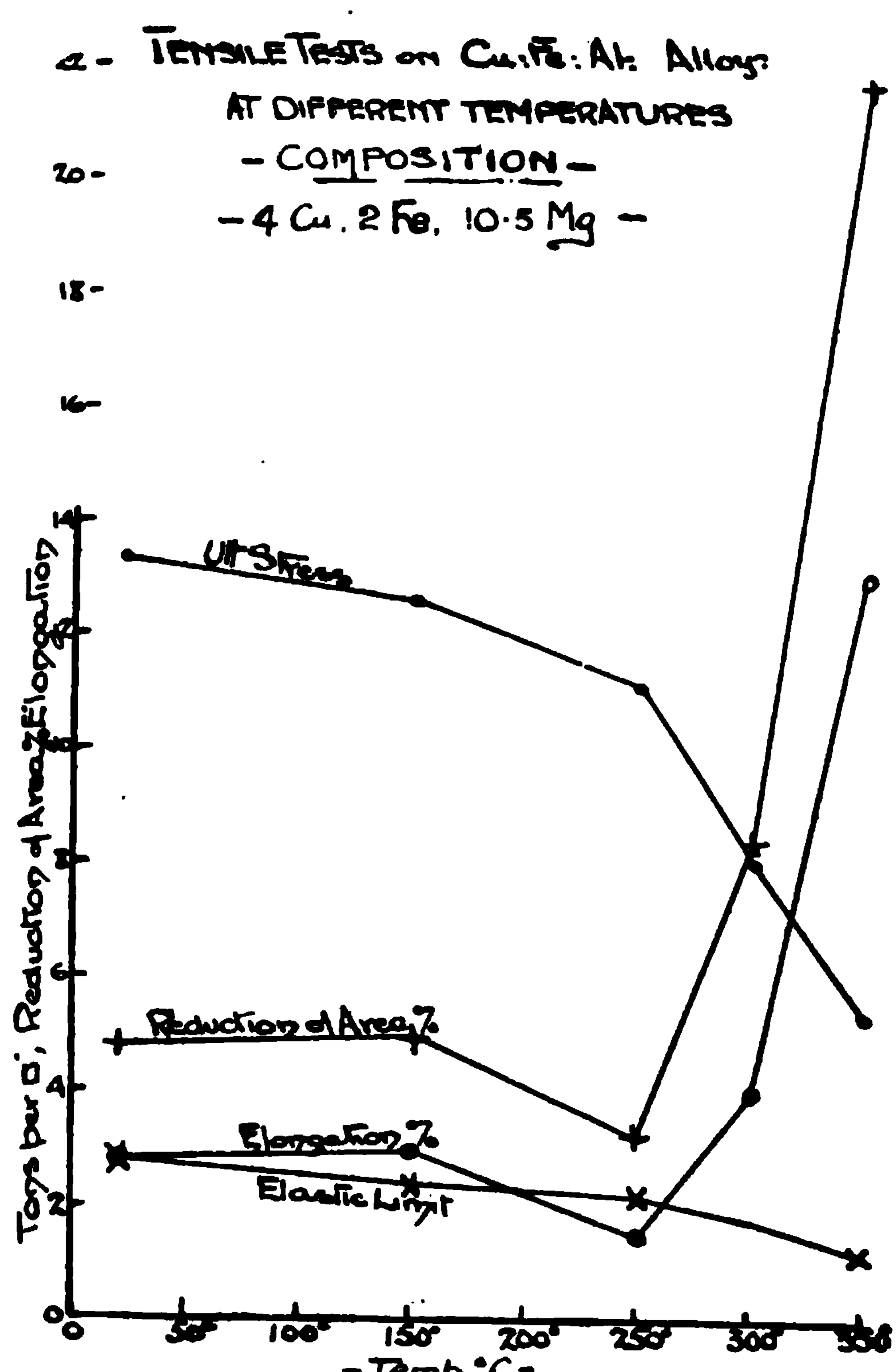



FIG. 19.—STRENGTHS OF COPPER-MAGNESIUM ALLOY AT DIFFERENT TEMPERATURES. (DR. LEA.)

This material gave a yield point of from 2·7 to 5·8 tons per square inch, and a tensile strength of from 6·7 to 9·5 tons per square inch, with from 1 to 3·5 per cent. elongation; its

specific tenacity being about 94. In the form of cold drawn wire it gave a tensile strength of 25 tons per square inch, but with no ductility, and in the annealed state 17 tons per square inch.

Evidently this alloy is inferior to most other commercial alloys of aluminium.

**Aluminium-Nickel Alloys.**

The effect of nickel upon aluminium resembles that of copper, and in the case of alloys containing both copper and nickel the properties of the alloy depend upon the total sum of the two, these elements being almost interchangeable.

The properties of alloys containing from 1 to 5½ per cent. of nickel and of ternary alloys of aluminium with from 0 to 8 per cent. of copper and from 0 to 8 per cent. of nickel have been investigated.*

The results obtained, however, led to the conclusion that none of the alloys was likely to be of much commercial importance. The best specific tenacity obtained for chill castings containing 2·1 per cent. copper and 5·33 per cent. nickel was 124. The same alloy gave the value 139 in the hot-rolled state and 162 in the cold-drawn state.

The following are a few typical results for these alloys—

TABLE XX.

PROPERTIES OF ALUMINIUM-NICKEL ALLOYS.

| *Composition.* | | *Condition.* | *Yield Point (tons per sq. inch).* | *Tensile Strength (tons per sq. inch).* | *Elongation in 2 inch per cent.* |
|---|---|---|---|---|---|
| *Aluminium* | *Nickel.* | | | | |
| 98·89 | 1·11 | Chill Castings | 2·6 | 6·63 | 20·8 |
| 96·0 | 4·0 | ,, ,, | 4·0 | 9·69 | 9 |
| 98·13 | 1·87 | Hot Rolled Rods | 5·4 | 8·12 | 28·4 |
| 95·69 | 4·31 | ,, ,, ,, | 6·0 | 9·96 | 22·0 |
| 95·69 | 4·31 | Ditto, annealed | 4·4 | 9·02 | 26·2 |
| 95·69 | 4·31 | Cold Drawn | 10·2 | 12·41 | 8·5 |

* "The Properties of Some Nickel-Aluminium and Copper-Nickel-Aluminium Alloys," A. A. Read and R. H. Greaves. *Journ. Inst. of Metals*, Mar., 1915.

Corrosion tests of these alloys showed that annealed specimens containing 1·42 to 2·25 per cent. of nickel lost 21 and 18 grains per square foot on immersion for 100 days in sea-water.

Pure aluminium under the same conditions lost from 6 to 12 grains. A ternary alloy containing 2·13 per cent. of copper and 3·74 per cent. of nickel lost only 10 grains.

## DURALUMIN

This quaternary alloy contains, besides aluminium, copper, manganese, and magnesium, there being over 90 per cent. of aluminium present.* The effect of the magnesium content is to harden the alloy, so that after thermal treatment, such as annealing, the metal gradually hardens to its maximum value in from 1 to 3 days; magnesium also imparts the characteristic odour to this metal. The specific gravity of this metal varies from 2·75 to 2·84, being about 2·8 upon the average, corresponding to a weight of 1·623 ounces per cubic inch, or 175·3 pounds per cubic foot.

Although only about one-third of the weight of mild steel, it has the same hardness and strength, so that for the majority of purposes duralumin can replace steel; for aircraft work the saving in weight effected by using this metal is considerable.

The *melting point* of duralumin is 650° C., and the temperature for *annealing* 350° to 380° C. It has a *specific heat* of 0·214 (water = 1), and a *thermal conductivity* of 31 (silver = 100). The *coefficient* of *linear* expansion per °C. is 0·0000226.

The following are typical analyses† of duralumin—

TABLE XXI.

ANALYSES OF DURALUMIN.

| *Copper.* | *Manganese.* | *Magnesium.* | *Silicon.* | *Iron.* | *Aluminium.* |
|---|---|---|---|---|---|
| 3·62 | 0·35 | 0·87 | 0·62 | 0·045 | Remainder |
| 3·0 | 1·0 | 2·0 | — | 1·0 | ,, |
| 3·6 | 0·4 | — | 0·5 | 0·6 | ,, |

* See also "Duralumin," by E. Unger and E. Schmidt. Tech. Berichte, Vol. III, Sect. 6. Trans. in "Aeronautics," Aug. 12, 1920.

† Kempe.

Duralumin is unaffected by mercury, or by ordinary atmospheric conditions, and is only very slowly acted upon by salt water. It is non-magnetic.

Duralumin can be obtained in the form of channels, angles, tees, tubes, bars, forgings, stampings, plates, sheets, strips, wire, screws, rivets, rolled or extruded sections, etc.

This alloy cannot, however, be cast.

**Mechanical Properties of Duralumin.***

Duralumin is obtainable in a variety of grades of strength and hardnesses, varying from 20 tons per square inch, with 25 per cent. elongation, up to nearly 40 tons per square inch, with from 2 to 4 per cent. elongation.

It is supplied commercially in bars and sheets in three qualities, *A*, *B*, and *D*, as follows—

| *Quality.* | *Tensile strength tons per square inch)* | *Elongation on 2 inches, per cent.* |
|---|---|---|
| *A* .. .. .. .. | 25–26 | 25–20 |
| *B* .. .. .. .. | 27 | 18–20 |
| *D* .. .. .. .. | 29 | 15–18 |

The harder grades are obtained by mechanical treatment, such as by forging, drawing, or rolling.

The following results* were obtained from ¼ inch duralumin plates rolled down to 0·08 inches thick, the strength tests being made at each reduction—

TABLE XXII.

STRENGTH OF ROLLED DURALUMIN PLATES.

| *Thickness of Plate.* | *Tons per square inch.* | | | | *Elongation on 2 inches, per cent.* | | *Hardness by Brinell.* | |
|---|---|---|---|---|---|---|---|---|
| | *Elastic Limit.* | | *Max. Stress.* | | | | | |
| *Inch.* | *A* | *D* | *A* | *D* | *A* | *D* | *A* | *D* |
| ·25 | 13·35 | 16·5 | 26·0 | 29·2 | 21·0 | 18·0 | 109 | 125 |
| ·22 | 24·73 | 27·3 | 28·6 | 32·4 | 10·0 | 7·0 | 131 | 144 |
| ·18 | 27·3 | 29·2 | 30·5 | 34·9 | 5·5 | 6·5 | 144 | 157 |
| ·15 | 29·8 | 31·1 | 31·7 | 36·2 | 5·0 | 5·0 | 148 | 159 |
| ·12 | 30·5 | 33·0 | 32·4 | 38·1 | 4·0 | 4·5 | 152 | 166 |
| ·08 | 31·1 | 34·3 | 33·6 | 39·4 | 2·3 | 3·0 | 158 | 174 |

Figures for quality *B* are intermediate to the above.

* Values given by Messrs. Vickers, Ltd.

The following results are the guaranteed ones for the commercial forms of duralumin.

## TABLE XXIII.

### STRENGTH OF DURALUMIN.

| Quality. | | Elastic Limit (tons per square inch). | Max. Breaking Strength (tons per square inch). | Elongation per cent. |
|---|---|---|---|---|
| SHEETS. | *A*—Normal .. | 13·5 | 25 | 20 |
| | *B*—Normal .. | 15 | 26 | 15–20 |
| | *B*—Hard .. | 20 | 30–32 | 10–12 |
| | *D*—Normal .. | 16·5 | 27–28 | 15 |
| | *D*—Hard .. | 24–27 | 35 | 5–7 |
| ROD. | *B*—Normal .. | 16–17 | 26 | 18 |
| | *B*—Hard .. | 20–22 | 32 | 6–10 |
| WIRE. | *B*—Normal .. | 16–17 | 26 | 18–20 |
| | *B*—Hard .. | 20–25 | 35 | 6–10 |
| TUBE. | *B* .. .. | 16–18 | 28 | 15–18 |

The ultimate breaking strength of annealed duralumin is approximately 65 per cent. of the figures given for the metal in its normal state.

The following results of compression tests upon duralumin refer to bars of the *B* quality.

## TABLE XXIV.

### COMPRESSION TEST RESULTS FOR DURALUMIN. (Vickers.)

| No. of Test Piece. | Dimensions before Test. | | Dimensions after Test. | | | |
|---|---|---|---|---|---|---|
| | | | Load, 10 tons. | Load, 17·5 tons. | Load, 25 tons. | Load, 30 tons. |
| | | Inch. | Inch. | Inch. | Inch. | Inch. |
| | Length | 1·0 | — | — | 0·997 | 0·990 |
| | Diameter | 1·125 | — | — | — | |
| | Length | 1·0 | — | 0·996 | — | 0·900 |
| | Diameter | 1·0 | — | 1·003 | — | 1·070 |
| | Length | 1·0 | 0·989 | — | — | 0·533 |
| | Diameter | 0·75 | 0·756 | — | — | 1·062 |

None of the samples showed any sign of bursting at the completion of tests.

The following particulars refer to the results of some corrosion tests, in which the duralumin plates were subjected to the alternate action of sea water and sea air respectively.

TABLE XXV.

RESULTS OF CORROSION TESTS UPON DURALUMIN. (Vickers.)

Plates exposed for twelve months to the action of sea water and sea air respectively. Loss measured in weight. Plates, 12 inches by 12 inches by 16 S.W.G.

| *Quality.* | *Weight before Immersion* | *Weight after Immersion* | *Total Loss.* | *Loss per square foot of surface exposed.* |
|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| No. 1. *B*—Normal | 412·39 | 411·75 | ·54 | ·27 |
| No. 2. *B*—Hard | 634·47 | 436·15 | ·32 | ·16 |
| No. 3. *A*—Normal | 412·08 | 409·20 | 2·88 | 1·44 |
| No. 4. *A*—Normal | 408·17 | 407·32 | ·85 | ·425 |

In the case of Nos. 3 and 4, local action has been set up in contact with the supporting frame along the edges of the plates, which accounts for the loss being greater than in the case of the *B* quality.

**Methods of Forging and Stamping Duralumin.**

Duralumin can be readily forged and hot-stamped, the resulting material varying in tensile strength from 24 to 28 tons per square inch. The following notes upon the working and heat treatment of forged and stamped parts are furnished by the manufacturers, Messrs. Vickers, Ltd.—

For forging or hot stamping work the metal should be uniformly heated to a temperature of from 400° to 420° C.

This is best performed by means of heating the material in a salt bath consisting of an iron or steel trough partly filled with a mixture of potassium and sodium nitrates, heated externally. Where the use of such a bath is impracticable a closed muffle furnace will be found to answer the purpose, but care should be exercised so that the metal is not burned during the annealing operation.

When it is required to put a considerable amount of work upon duralumin in the finished state, such as sheets, bars, and sections, it may be found necessary to anneal. Such annealing should be done at 350° to 360° C. and the metal should be quenched in water. Moreover, if several operations are to be performed, it will be necessary to anneal between such operations, precisely the same as for brass, and such work should be put on the metal immediately after quenching, otherwise it becomes too hard.

The heated quenched material hardens gradually during the first four days, after which no further hardening takes place. This is one of the most remarkable properties possessed by duralumin.

### Applications.

Duralumin has been extensively used in aircraft constructional work, in connexion with the girder work of rigid airships, aeroplane spars, clips, and fittings. It is also applicable to surgical and orthopaedic work, for light, transportable structures.

Duralumin, being much stronger than aluminium, is now being used for motor body and panel work, bonnets and automobile fittings; it is also frequently employed for non-magnetic and other instrument parts.

#### Air Ministry Specifications for Duralumin Sheet.

1. Application.—For parts which require to be light, non-corroding, and non-magnetic.

2. Alloy.—The alloy is to consist of materials of the best quality, and must not contain more than 1 per cent. of total accidental impurities.

3. The specific gravity is not to exceed 2·85.

4. SHEETS.—Sheets are to be sound, clean, and free from all surface defects.

5. All sheets are to be of uniform thickness and to the dimensions specified. A variation in thickness to the extent of the following limits will be tolerated—

| | | |
|---|---|---|
| For I.W.G. of 23 and over | .. .. .. | + or − ·001 inch. |
| „ „ 19 to 22 inclusive | .. .. | + or − ·002 „ |
| „ „ 14 to 18 „ | .. .. | + or − ·004 „ |
| „ „ 6 to 13 „ | .. .. | + or − ·006 „ |

6. TESTS.—Test specimens taken from any sheet are to comply with the following mechanical test—

*Tensile Test.*

| | | |
|---|---|---|
| Ultimate Stress | .. .. | 25 tons per square inch. |
| Yield Point | .. .. .. | 15 „ „ „ |

The tensile test is to be carried out on a specimen 4 inches long (test length) × 1·25 inches wide × gauge thickness, for which purpose two pieces not less than 10 inches × 2 inches × gauge thickness must be submitted.

7. The above test values are minima. If any one of the test pieces fails to pass the specified tests, the sheet or sheets represented by the defective specimen will be rejected.

8. No test piece will be annealed, hammered, or otherwise treated after its removal from the sheet.

9. The manufacturer must bear the cost of the depreciation in value of any rejected material due to test pieces being cut therefrom.

## AIR MINISTRY SPECIFICATIONS FOR DURALUMIN BAR.

1. APPLICATION.—For parts which require to be light, non-rusting, and which are fairly highly stressed.

2. ALLOY.—The alloy is to consist of materials of the best quality, and is to be free from all injurious impurities.

3. The specific gravity is not to exceed 2·85.

4. BARS.—Bars as supplied by the manufacturer are not to be heated in any way during or after machining.

5. The bars are to be sound, straight, free from twists, seams, and damaged ends, and must have a workmanlike finish. They are to be uniform in quality and capable of being machined easily and of taking a good finish.

6. The sizes of the bars are to be within the margin of manufacture, as laid down by the E.S.C. in their *Report No.* 32 (1907), pp. 9 and 10.

7. TESTS.—Test specimens taken from any bar are to comply with the following mechanical tests—

(*a*) *Tensile Test.*—

| | *For Bars under 2⅝ inches diameter.* | *For bars 2⅝ inches diameter and over.* |
|---|---|---|
| Ultimate Stress .. | 25 tons per sq. inch | 17 tons per sq. inch |
| Yield Point .. .. | 16 „ „ „ | 10 „ „ „ |
| Elongation on 2 inches | 15 per cent. | 15 per cent. |
| Reduction of area .. | 20 „ | — |

The tensile test is to be made on the British Standard Test Piece (·564 inches diameter × 2 inches long), or on a specimen which has the same geometrical proportions.

(*b*) *Shear Test.*—If the duralumin is supplied in the form of rivets it must comply with the following additional test—

Shear Stress .. .. .. 14 tons per square inch.

8. These test values are minima. If any one of the test pieces fails to fulfil any one of these tests the bar or bars represented by the defective specimen will be rejected.

9. No test piece will be annealed, hammered, or otherwise treated after its removal from the bar.

10. The manufacturer must bear the cost of the depreciation in value of any rejected material due to test pieces being cut therefrom.

## Air Ministry Specification for Duralumin Tubes.

### (Extract.)

1. Material and Manufacture.—The tubes are to be solid-drawn seamless tubes made of duralumin alloy of specific gravity not exceeding 2·85.

The tubes are to be straight, smooth, cylindrical, of uniform quality and sectional thickness, and of equal diameter throughout, free from dirt specks, seaming, blisters, lamination, grooving, or other surface defects.

2. Toleration.—The diameter of the tubes is not to differ at any point from the size specified by more than—

For tubes under 2 inches diameter .. .. ± ·003 inch.
For tubes of 2 inches and up to 3 inches .. ± ·005 inch.

The mean thickness of the tubes is nowhere to be less than the specified gauge or to exceed it by more than ·004 inch for tubes less than ·08 inch thick, or by more than 5 per cent. for thicker tubes. Any variations of thickness due to eccentricity of the bore is not to exceed ± 10 per cent. of the specified thickness.

3. Tests.—The tubes are to comply with the following mechanical tests.

*Tensile Tests.*—A test piece consisting of a short length cut off the tube must, without further heating or other manipulation, show an ultimate strength, yield point, and elongation not less than the following—

| | *Ultimate stress (tons per sq. inch).* | *Yield point (tons per sq. inch)* | *Elongation on 2 inches per cent.* |
|---|---|---|---|
| Tubes up to ·06 inch thick .. | 25 | 16 | 8 |
| „ between ·06 and ·1 in. thick | 25 | 16 | 10 |
| „ over ·1 inch thick .. | 25 | 16 | 12½ |

## MAGNALIUM

Magnalium is an alloy of aluminium and magnesium of the following approximate composition—

| | *Per cent.* |
|---|---|
| Aluminium .. .. .. | 90–98 |
| Magnesium, etc. .. .. .. | 10–2 |

Apart from magnesium there is also present small quantities of copper, nickel, lead, or tin. The following are typical analyses of the commercial magnalium metals—

TABLE XXVI.

COMPOSITION OF MAGNALIUM.

| *Condition.* | *Proportions. Per cent.* | | | | | |
|---|---|---|---|---|---|---|
| | *Copper* | *Magnesium* | *Nickel* | *Tin* | *Lead* | *Aluminium* |
| Strong Castings | 1·76 | 1·60 | 1·16 | — | — | Remainder |
| Ordinary Castings | 1·76 | 1·60 | — | traces | traces | „ |
| Rolled or Drawn | 0·21 | 1·58 | — | 3·15 | 0·72 | „ |

It is lighter than aluminium, its specific gravity being 2·5, and is also whiter in colour, harder, and stronger.

It can be rolled, forged, cast, drawn, filed, and machined, and is noted for its non-corrosive properties.

The following are the strength properties of this metal—

TABLE XXVII.

THE STRENGTH PROPERTIES OF MAGNALIUM.

| *Condition.* | *Tensile Strength (tons per square inch)* | *Reduction of Area, per cent.* |
|---|---|---|
| Cast .. .. .. | 8·2–9·5 | 3·75 |
| Rolled .. .. .. | 23·0 | 3·7 |
| Annealed .. .. .. | 18·8 | 17·8 |

Magnalium in the finely divided state is very inflammable, and several accidents have resulted through the neglect to take suitable precautions during the working processes

## NAVALTUM

This is another of the aluminium-magnesium alloys, which has been employed in aircraft and marine work. It has a specific gravity varying from 2·2 to 2·8 and a tensile strength varying from 9 to 25 tons per square inch.

The following are the results of some tests made upon this metal—

TABLE XXVIII.

PROPERTIES OF NAVALTUM. (Faraday House.)

| *Condition and Size of Test Piece.* | *Tons per sq. inch* | | *Elongation, per cent.* | *Reduction of Area, per cent.* | *Specific Gravity.* | *Remarks.* |
|---|---|---|---|---|---|---|
| | *Yield point.* | *Tensile strength.* | | | | |
| Cast bar (0·32 inch dia.) | 7·77 | 16·17 | 12·0 | 52·7 | — | Silky fracture |
| Rolled bar (0·396 inch) dia. | 21·63 | 25·28 | 13·7 | 37·7 | 2·79 | Fracture finely granulated |

This metal is supplied in the drawn, rolled, spun, forged, or cast condition, and in the form of sheets, tubes, rods, strip, wire, and other forms. The shrinkage allowed for navaltum castings is $\frac{3}{16}$ inch per foot.

## VANALIUM

This aluminium alloy is about 3 per cent. heavier than aluminium and can be obtained in the cast form with a yield point of 8 tons per square inch, and tensile strength of 11 tons per square inch, with a corresponding elongation of 8 per cent. in 2 inches. By rolling or drawing its strength can be increased from 2 to 3 times, but with loss in elongation.

This metal is stated to be unaffected by sea water, atmospheric conditions, sulphuretted hydrogen, carbon-dioxide, or sulphurous waters. It is said to have the property of retaining its hardness after heating better than other known aluminium alloys, and it can be easily soldered with a special solder supplied by the makers. Its melting point is about 650° C.,

and the shrinkage of the metal after casting is from 1·5 to 2 per cent.

It can be supplied in the form of sheets, rods, sections, wires, and castings, and is applicable to aeronautical and automobile work.

## WOLFRAMINIUM

This is an alloy of aluminium, with copper and tungsten. It has a specific gravity of 2·86 in the cast state and 3·09 in the rolled condition.

Its tensile strength in the cast state varies from 7·5 to 10·8 tons per square inch, with from 12 to 6 per cent. elongation, and in the rolled state from 20 to 24 tons per square inch, with from 8 to 6 per cent. elongation. In the annealed condition its specific gravity is about 2·7, with a tensile strength of 17 tons per square inch, with 16 per cent. elongation.

This metal has been employed in France for motor car body-work, on account of its ductility, good surface, and non-tarnishing qualities.

## ROMANIUM

This is an alloy of aluminium with tungsten and nickel, having a specific gravity of about 2·75.

It is harder and more elastic than wolframinium, but gives about the same tensile strength values.

It is obtainable in the form of sheets, plates, bars, hot or cold forgings, stampings, and pressings.

TABLE XXIX.

PROPERTIES OF ROMANIUM.

| *Condition.* | *Tensile strength (tons per sq. inch).* | *Elongation, per cent.* | *Specific gravity.* |
|---|---|---|---|
| Hand Rolled | 23·76 | 5·0 | 2·75 |
| Annealed .. | 17·09 | 19·4 | 2·71 |

## ALUMINIUM ALLOYS IN AUTOMOBILE WORK

For petrol engine castings, such as the crank-cases, covers, clutches, pistons, etc., it is usual to employ aluminium alloys which cast well, and which give high strength values combined with maximum resistance to vibration.

A typical alloy recommended for automobile work is one of the copper series containing about 8 per cent. of copper and 92 per cent. of aluminium, with a small amount of nickel or manganese. This alloy has a specific gravity of about 2·85 and a tensile strength of from 8 to 9½ tons per square inch.

The casting alloys given in Table V are also very suitable for automobile castings.

### Crank-Case Alloys.

For crank-case work alloys having from 2 to 3 per cent. of copper and from 10 to 14 per cent. of zinc are found to be satisfactory. They have a specific gravity of less than 3, and are easy to use in the foundry and machine shop. The alloy, first made by Dr. Rosenhain, known as *L5*, and containing from 12 to 14 per cent. of zinc and from 2½ to 3 per cent. of copper, has been largely used recently, and gives good castings. It gives a tensile strength in the chill-cast state of about 13 tons per square inch, with an elongation on 2 inches of about 2 per cent. In the sand-cast state a tensile strength of 12 tons per square inch, with 1·75 per cent. extension is obtained.

The results of Wöhler tests showed that in the case of the chill-cast metal, with a maximum range of stress of from $6{\cdot}16 \pm 3{\cdot}08$ tons per square inch, the metal just stood up, but with a range of $7{\cdot}57 \pm 3{\cdot}785$ tons per square inch, 774,216 cycles caused fracture, and with a range of $7{\cdot}0 \pm 3{\cdot}5$ tons per square inch, it took nearly 4 million cycles to cause fracture.

This alloy is also suitable for smaller parts of engines, such as induction pipes, carburettors, and centrifugal pumps. Fig. 20 shows a typical example of a cast aluminium

rear-axle casing* used upon motor lorries, whilst Fig. 21 shows a cast aluminium dashboard.

The composition of the alloy, giving the above-mentioned mechanical results, was as follows—

| | *Copper.* | *Zinc.* | *Tin.* | *Iron.* | *Silicon.* | *Per cent.* |
|---|---|---|---|---|---|---|
| Sand Cast | 2·17 | 12·13 | 0·06 | 0·73 | 0·30 | — |
| Chill Cast | 2·07 | 11·40 | 0·05 | 0·62 | 0·27 | — |

The remainder in each case being aluminium.

FIG. 20.—CAST ALUMINIUM REAR AXLE CASING.

The following is an analysis of the aluminium alloy used for the crank-case castings of a very successful aeroplane engine—

| | *Per cent.* |
|---|---|
| Aluminium .. .. .. .. | 80·36 |
| Copper .. .. .. .. | 4·22 |
| Zinc .. .. .. .. .. | 3·65 |
| Silicon .. .. .. .. | 0·96 |
| Iron .. .. .. .. .. | 0·81 |

* Designed by The Daimler Co., Ltd.

The mechanical properties of this alloy are as follows—

| | |
|---|---|
| Yield Point .. .. .. .. | 8·7 tons per square inch |
| Tensile Strength .. . .. | 9·35 ,, ,, ,, |
| Elongation on 2 inches .. .. | 3·55 per cent. |
| Reduction of Area .. .. .. | 3·5 ,, |
| Specific Gravity .. .. .. | 2·867 ,, |

FIG. 21.—CAST ALUMINIUM DASHBOARD

## Air-Cooled Aluminium Cylinders.

Fig. 22* illustrates a 100 millimetre bore by 140 millimetre stroke air-cooled aeroplane engine cylinder, fitted with a steel liner (open ended) which is not, however, shown in the diagram.

The alloy used for this cylinder consisted of 7 per cent. copper, 1 per cent. zinc, 1 per cent. tin, and 91 per cent. aluminium.

The cylinders were so designed that very efficient valve port cooling was attained, and the surface temperature of the metal was kept well below 300° C.

* *Aeron. Journal*, Nov., 1919.

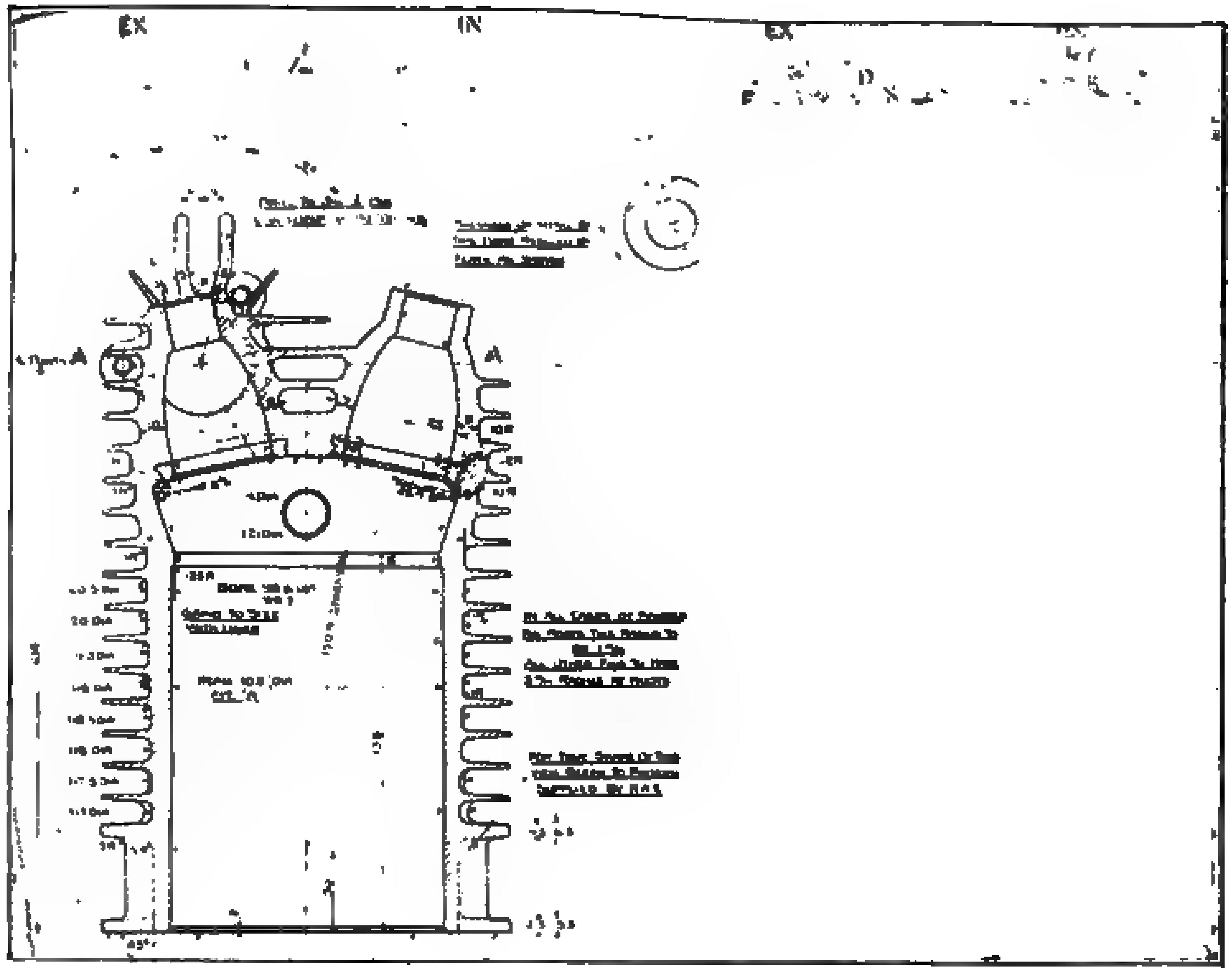



FIG. 22.—ALUMINIUM AIR-COOLED ENGINE CYLINDER.

When the temperature of the metal exceeds 300° C., the metal is very apt to crack.

The total areas of the cooling surfaces of this series of cylinders were as follows—

| *Cylinder.* | *Surface in sq. feet.* | *Pitch of Fins.* |
|---|---|---|
| 100 × 140 millimetres (aluminium) | 6·14 | 12 millimetres |
| 114 × 140 millimetres ,, | 8·4 | 9 ,, |
| 100 × 140 millimetres (cast iron) | 4·7 | 8 ,, |

In the case of the first engine, the results of engine tests made at speeds of 1400, 1600, and 1800 R.P.M. respectively, showed that the thermal efficiency was never below 25 per cent., and the relative efficiency compared with the air standard cycle was 58 per cent.

The velocity of the cooling air at a point 6 inches ahead of the cylinder centre line was 64 miles per hour, which corresponded with a mean air speed of 58 miles per hour. The cooling air temperature was 60° F.

The maximum temperature recorded in the aluminium cylinder was 175° and the minimum 129°. The maximum cylinder liner temperature was 144°.

In the case of the cast iron cylinder the maximum temperature recorded was 268° and the minimum 171°.

The coefficient of conductivity of aluminium has been given as being about three times that of cast iron, and for an equal weight, the walls of an aluminium piston will be thicker, of course, so that the mean temperature of the piston will be less. The use of aluminium for pistons enables higher engine compressions to be used. In connexion with the use of aluminium cylinders* in place of cast iron, the following analysis will illustrate the advantages to be gained in employing this metal or its alloys.

* *Vide* also "Aluminium Alloys for Aeroplane Engines," F. C. Lea, *Aeron. Journal*, Nov., 1919.

Let $\rho$ and $\rho_1$ be the densities of cast iron and aluminium respectively, $k$ and $k_1$ the conductivities, and $t$ and $t_1$ the mean thicknesses of the cylinder walls through which the heat flows. Then, assuming the same cylinder weights—

$$\frac{\rho}{\rho_1} = \frac{t_1}{t}$$

If T and $T_1$ be the temperature of the hot wall of the cast iron and aluminium cylinders respectively, and $T_o$ that of the outer or cold wall in each case, then the ratio of the heat flows through the cast iron and aluminium cylinders is given by—

$$\frac{H_I}{H_A} = \frac{(T - T_o)\,k\,t_1}{(T_1 - T_o)\,k_1 t}$$

For the same hot wall temperatures $T = T_1$ and therefore

$$\frac{H_1}{H_A} = \frac{kt_1}{k_1 t} = \frac{k}{k_1 \rho_1}$$

Substituting values $\frac{\rho}{\rho_1} = 2{\cdot}7$ and $\frac{k}{k_1} = 3$ (about),

$$\text{so that } \frac{H_A}{H_1} = 1{\cdot}25.$$

Hence, for the same weights of cylinders the aluminium shows a 25 per cent. superiority as a cooling metal, and as in practice the aluminium cylinders are much lighter than the cast iron ones, a still greater superiority results.

## Water-Cooled Aluminium Cylinders.

Aluminium alloys are now becoming widely used for the castings of automobile and aircraft engine cylinders. These alloys, particulars of which will be given later, possess the following advantages over cast iron—

(*a*) That they give a considerable saving in weight.

(*b*) That as the thermal conductivity is about three times that of cast iron, far better cooling results.

(*c*) That higher compressions can be employed.

It is only by the extended use of aluminium for cylinders and other parts of the engine that the weight of aircraft engines has been reduced down to $1\frac{1}{2}$ to $2\frac{1}{2}$ pounds per B.H.P. The usual method adopted for cylinder castings is to fit a thin steel or cast iron liner to each cylinder barrel; this liner may be either closed at the combustion chamber end, so as to form a kind of cup, or left open in the form of a tube. The latter method appears to be the most favoured, as it is not only cheaper but leaves the combustion head of aluminium exposed to the working charge, so that better heat elimination occurs.

The steel liner is sometimes in contact throughout its length with the aluminium barrel, with the water-jacket space outside, or is only in contact with the aluminium at the two ends, its outer surface being directly in contact with the water; the latter arrangement is probably the better. Recent American practice for the elimination of aluminium between the steel or cast iron liner is for the liners to be packed with a copper-asbestos jacket at the bottom, the cylinder head gasket forming the joint at the top. This method ensures equal expansion and transmission of heat to the water, and if aluminium pistons are used the clearance can be reduced to one-half.

The valve seats, in the above cases, cannot be made of aluminium, nor may the valve guides. One successful method of overcoming this difficulty is to cast in small pieces of suitably shaped cast iron or bronze to form the valve seatings or guides.

Fig. 23 illustrates a four-cylinder aluminium alloy block casting, cast in one piece with the top half of the crank-case; the timing casing is also integral with the rest of the casting.

Fig. 24 shows an eight-cylinder vee-type aluminium block casting, designed for detachable cylinder heads (also of aluminium) with cast iron valve seats.

FIG. 23.—FOUR-CYLINDER ALUMINIUM BLOCK CASTING.

FIG. 24.—EIGHT-CYLINDER VEE-TYPE BLOCK CASTING IN ALUMINIUM.

## Alloys for Cylinder Castings.

The following table* gives the percentage compositions of aluminium alloys which have been used for the cylinder castings of aircraft and automobile engines—

| *Aluminium* | *Copper* | *Tin.* | *Zinc.* | *Iron* | *Manganese* | *Magnesium* |
|---|---|---|---|---|---|---|
| 88 | 12 | — | — | — | — | — |
| 87 | 12 | — | — | — | 1 | — |
| 91 | 8 | — | — | — | 1 | — |
| 91 | 7 | 1 | 1 | — | — | — |
| 87 | 9 | 2 | 2 | — | — | — |
| 89¾ | 10 | 1¼ | — | — | — | — |
| 90 | 10 | — | — | — | — | — |
| 93½ | 4 | — | — | 2 | — | ½ |

The best results appear to be obtained with an alloy containing 10 per cent. of copper, with or without from 1 to 2 per cent. of tin. There is a range of alloys containing from 5 to 12 per cent. of copper, and from 1 to 2 per cent. of tin, which gives good castings ; it is thought that the addition of the tin promotes greater fluidity in the molten metal.

The following is the composition of the aluminium cylinder castings (jackets) for the Hispano-Suiza engines—

| | *Per cent.* |
|---|---|
| Copper | 7·84 |
| Zinc | 6·33 |
| Iron | 0·44 |
| Silicon | 0·27 |
| Aluminium | 85·12 |

## Aluminium Pistons.

The use of aluminium for petrol engine pistons has found almost universal favour in aircraft and high-grade aero. engine practice of late.

The principal advantages of a suitable aluminium alloy piston over a cast iron one is that, owing to its better heat conductivity (which is about three times that of cast iron), it enables the pistons to run cooler, and therefore is more favourable to the use of higher engine compressions.

* See Footnote, p. 64.

The specific gravity of the average aluminium piston metal is only about one-third that of cast iron, and the weight of an aluminium piston can therefore be made much lower than that of a cast iron one, although not in proportion to the densities of the metal, since strength and other design factors are involved. The relative heat flows for the same temperature gradients for aluminium and cast iron are approximately in the ratio of 1·5 to 1·0.

In connexion with the reduced weight of aluminium pistons, it is possible to obtain a 50 per cent. reduction in weight over the cast iron ones, in the slipper type of piston, so that the reciprocating forces due to the combined weight of the piston and connecting rod can be very appreciably reduced.

In the case of a four-cylindered light car engine of 2¾ inches bore and 4 inches stroke, the substitution of aluminium pistons weighing 0·64 pounds each for cast iron ones weighing 1·37 pounds each, resulted in an increase in the brake horse-power at all speeds, and at the maximum speed of 2400 R.P.M. the B.H.P. was increased from 19·0 to 21·6; that is, an increase of about 13 per cent.

Figs. 25 and 26 illustrate the Ricardo type of aluminium piston, which gives about the lightest weight of any type. In the case of a 4 inch bore cylinder the respective weights of the Ricardo slipper type, the aluminium trunk type and the light cast iron type were 1·0, 1·4, and 2·8 pounds respectively. The piston friction of the Ricardo type has been shown to be about 60 per cent. of that of the ordinary cast iron type at normal working speeds.

Special precautions are necessary when substituting aluminium alloy pistons for cast iron ones, in connexion with the cylinder clearances allowed, the support of the piston crown, and the effective lubrication of the walls. The pistons are made with larger clearances than in the case of cast iron, owing to the greater coefficients of expansion of aluminium, and to what is known as the "growth" of the metal.

FIG. 25.—THE RICARDO SLIPPER PISTON.

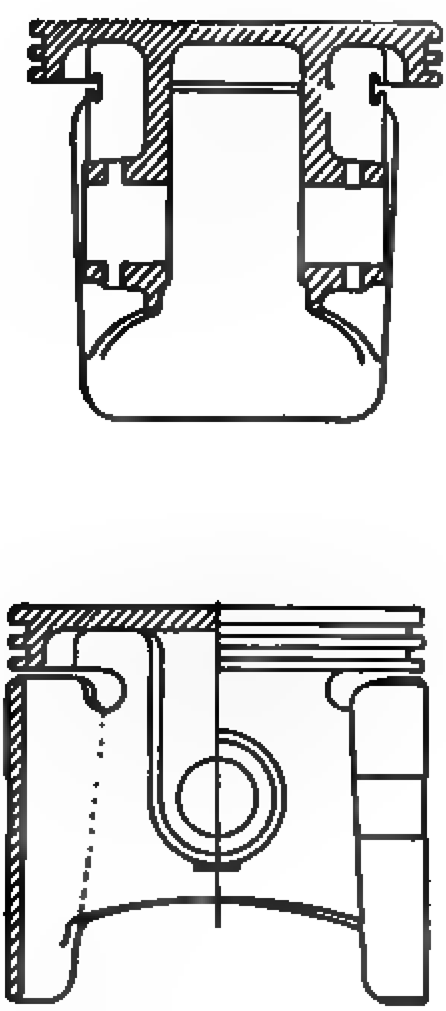


FIG. 26.—SECTIONAL VIEWS OF THE RICARDO SLIPPER PISTON.

**Growth of Aluminium.**

Growth takes place to a small extent when the metal is heated to 260° C. or more, but the possible growth is small compared with the probable relative thermal expansion of the metal. The possible relative expansion of a piston of 120 millimetres (or 4·7 inches) diameter may be as great as $\frac{20}{1000}$ inch, whereas the growth of the piston would not exceed $\frac{5}{1000}$ inch. By annealing pistons made of various aluminium alloys at temperatures varying from 200° C. to 410° C. for different periods of time, the growth of aluminium pistons can be reduced to less than $\frac{1}{1000}$ inch per inch diameter of piston.

Some experiments made at the R.A.E. showed that under running conditions the growth of a 4 inch piston ceased after 30 hours running, and in a piston made of an alloy containing 7 per cent. copper, 1 per cent. tin, and 1 per cent. zinc, the growth after 40 hours was only $\frac{2}{1000}$ inch. Another piston containing 14 per cent. copper and 1 per cent. manganese grew $\frac{4{\cdot}4}{1000}$ in 55 hours.

The mean coefficient of expansion for aluminium piston alloys may be taken at $26 \times 10^{-6}$.

**Thermal Expansion of Aluminium Pistons.**

It has already been mentioned that the expansion of aluminium alloys is from 3 to 4 times the actual growth; it is about 2½ times greater than that of cast iron, so that greater piston clearances are necessary. The thermal expansion of aluminium may be as great as $\frac{4}{1000}$ to $\frac{6}{1000}$ inch per inch of piston diameter when steel or cast iron liners are employed.

In the case of a well-known twelve-cylinder aeroplane engine of 145 millimetre bore, the diameter of the piston at the top is 143·9 millimetres, and at the bottom 144·3 millimetres, so that the allowance for expansion (and possible

growth) is 1·1 millimetre (or about $\frac{43}{1000}$ inch) at the top and 0·7 millimetres (or about $\frac{27}{1000}$ inch) at the bottom of the piston. The maximum difference of temperature between the aluminium piston and the liner is about 100° C. in the case of a water-cooled engine.

In the case of an air-cooled aircraft engine the maximum temperature of the aluminium alloy piston was 240° C., and of the liner 145° C.; when a cast iron piston was used, the maximum temperature was over 400° C.

Taking a temperature difference of 100° C., and denoting the cylinder liner temperature by $t$° C., and the coefficients of expansion of aluminium and steel as $26 \times 10^{-6}$ and $10 \times 10^{-6}$, then the relative expansion of the aluminium and the steel liner will be—

$$\begin{aligned} e &= d\,\{(100 + t)\cdot 26 - 10t\} \times 10^{-6} \\ &= d\,(2600 + 16t) \times 10^{-6} \end{aligned}$$

where $d$ = diameter of cylinder.

For example, in the case of a 120 millimetre (or 4·7 inches) diameter piston, and with a cylinder liner temperature of 150° C., we have

$$\begin{aligned} e &= 4\cdot 7\,(2600 + 2400) \times 10^{-6} \\ &= 23\cdot 5 \times 10^{-3} \end{aligned}$$

$$\text{or} \quad \frac{23\cdot 5}{1000} \text{ inch.}$$

Making an allowance of $\frac{4}{1000}$ inch for growth and $\frac{2\cdot 5}{1000}$ inch for possible distortion, the total clearance between the cylinder and piston will be $\frac{30}{1000}$ inch.

For a piston of 145 millimetres diameter it will therefore work out at

$$\frac{145}{120} \times \frac{30}{1000} = \frac{36}{1000} \text{ inch,}$$

which value agrees fairly well with the mean of the values in the example given earlier.

In some instances too much piston clearance gives rise to piston slap at low speeds and during the warming up process; this is sometimes prevented by giving less clearance at the skirt of the piston and splitting same for a short distance from the lower edge, so as to obtain a spring effect as shown in Fig. 27.

A light steel spring ring is sometimes used inside the split skirt to ensure the necessary spring. It is usual with aluminium pistons to drill a number of small holes right through

FIG. 27.—SPLIT SKIRT PISTON (AEROLITE).

the skirt or walls, so as to enable the surplus oil, due to the greater clearances, etc., to drain off, back inside the piston.

## Compositions of Piston Alloys.

It has been shown by test that high copper aluminium alloys are superior to high zinc alloys for all piston and other castings which are exposed to high temperatures, and that these alloys are hardened by the addition of magnesium. The following results refer to tensile tests of different alloys

at various temperatures, and will serve to show the influence of the composition of the metal upon its strength at different temperatures.

| *Condition.* | *Composition, per cent.* | | | | | | | *Tensile strength in tons per square inch.* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Copper* | *Manganese* | *Tin* | *Zinc* | *Iron* | *Nickel* | *Magnesium* | 50°C. | 200°C. | 350°C. |
| Chill cast | 14 | 1 | — | — | — | — | — | 9·3 | 9·8 | 6·3 |
| " " | 7 | — | 1 | 1 | — | — | — | 9·2 | 6·7 | 3·2 |
| Sand " | 7 | — | 1 | 1 | — | — | — | 6·2 | 5·2 | 2·3 |
| Chill " | 14 | 1 | — | — | — | — | — | 8·3 | 8·6 | 8·4 |
| " " | 4 | — | — | — | 2 | — | 0·5 | 12·1 | 11·4 | 6·0 |
| " " | 12 | — | — | — | 0·8 | — | — | 13·1 | 11·9 | 7·4 |
| " " | 4 | — | — | — | — | 2 | 1·5 | 12·8 | 13·2 | 5·6 |
| Sand " | 4 | — | — | — | — | 2 | 1·5 | 11·2 | 11·2 | 5·0 |
| Chill " | 8 | — | — | — | — | 2 | 1·5 | 10·2 | 9·7 | 4·4 |
| Sand " | 8 | — | — | — | — | 2 | 1·5 | 8·6 | 8·2 | 4·0 |

In the case of the alloy containing 12 per cent. copper, and 0·8 per cent. iron, the percentage elongations at 50°, 200°, and 350° C. were 1·6, 1·6, and 18·0 respectively.

The high copper alloys will be seen to give the highest strength values at 350° C.

The Brinell hardnesses of the above alloys were found to vary from about 55 to 80 at 15° C. and from about 10 to 15 at 400° C., the high copper alloys giving the best results.

A Benz aluminium piston containing about 1½ per cent. of iron, and a high percentage of copper and zinc was found to have a Brinell hardness of 62 when cold, 28 at 300° C., and 11 at 400° C. The tensile strength when cold was 13 tons per square inch, and at 300° C., 4·1 tons per square inch.

The following is a more detailed analysis of one of the above types of aeroplane engine piston alloy—

| | *Per cent.* |
|---|---|
| Aluminium .. .. .. .. .. | 80·12 |
| Copper .. .. .. .. .. | 6·02 |
| Zinc .. .. .. .. .. | 12·13 |
| Iron .. .. .. .. .. | 1·24 |
| Silicon .. .. .. .. .. | 0·31 |

In the case of another six-cylinder 270 H.P. aeroplane engine, the piston had the following composition—

| | Per cent. |
|---|---|
| Aluminium .. .. .. .. .. | 80·97 |
| Copper .. .. .. .. | 1·90 |
| Zinc .. .. .. .. .. | 15·62 |
| Iron .. .. .. .. .. | 1·06 |
| Tin .. .. .. .. .. | Nil |
| Manganese .. .. .. .. | Nil |
| Silicon .. .. .. .. | 0·45 |

In considering the various possible piston alloys, such as those given in the preceding table, it will be seen that a suitable alloy would be one containing about 4 per cent. copper, with either nickel or iron, together with magnesium varying from 0·5 to 1·5 per cent. This alloy has quite as good properties as those of the 12 per cent. copper alloy, and, in addition, possesses the advantage of greater lightness.

The Brinell number of the 12 per cent. copper alloy is 33 at 300° C., while that of the 4 per cent. copper, 2 per cent. nickel, 1½ per cent. magnesium is 56·7.

There are certain foundry difficulties, however, in the case of the latter alloy, but these may be overcome.

The following are further examples of aluminium alloy piston compositions* that have been used in this country and in America—

| *Description.* | *Composition, per cent.* | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Aluminium* | *Copper* | *Nickel* | *Zinc* | *Iron* | *Magnesium* | *Silicon.* |
| 12 per cent copper Pistons .. .. | 87·79 | 11·94 | — | — | 0·69 | — | 0·28 |
| Lynite Piston (U.S.A.) | 89·11 | 8·96 | — | — | 1·30 | 0·27 | 0·36 |
| Benz Piston.. .. | 80·12 | 6·02 | — | 12·13 | 1·42 | trace | 0·31 |
| Birmingham Benz Piston Alloy .. | 80·12 | 5·44 | — | 12·27 | 1·41 | trace | 0·31 |
| Clerget Piston .. | 81·30 | 11·63 | 0·91 | 5·39 | 0·46 | — | 0·31 |

## Motor Car Radiator Alloy.

The following is the composition specification† of the aluminium alloy employed for automobile radiators (lorry

* "Aluminium Alloys for Aeroplane Engines," Prof. F. C. Lea, *Aeron. Journ.*, Nov., 1919.

† "Materials for Motor Bus Construction," *Engineering*, 17th Jan., 1913.

and motor bus), and for similar parts requiring closeness of grain and high strength with rigidity—

| | Per cent. |
|---|---|
| Aluminium .. .. .. .. .. | 86–88 |
| Copper .. .. .. .. .. | 14–12 |

Another alloy suitable for such parts, and also for crank-cases, is as follows—

| | Per cent. |
|---|---|
| Aluminium .. .. .. .. .. | 84·9–83·1 |
| Copper .. .. .. .. .. | 2·5– 3·0 |
| Iron .. .. .. .. .. | 0·4– 0·6 |
| Zinc .. .. .. .. .. | 12·0–13·0 |
| Silicon .. .. .. .. .. | 0·2– 0·3 |

**Connecting Rod Alloys.**

In concluding this section, reference must be made to the possibilities of aluminium alloys for the connecting-rods. From analytical considerations, it does not appear likely that any present-day aluminium alloy will replace properly heat-treated alloy steel for petrol engine connecting-rods.

The lightest material for a given tensile or compressive load is the one giving the greatest value for the ratio

$$\frac{\text{stress}}{\text{specific gravity}}$$

In the case of oil-hardened nickel-chrome steel, this ratio is given by—

$$\frac{\text{100 tons per square inch,}}{7{\cdot}8} \text{ or } 12{\cdot}9$$

and in the case of duralumin, by—

$$\frac{\text{30 tons per square inch}}{2{\cdot}8} \text{ or } 10{\cdot}7.$$

So that the alloy steel shows a superiority over the aluminium alloy.

It is further known that aluminium alloys are not so strong, relatively, under repeated stress or impact, as alloy steels, and for this reason also the alloy steel has the advantage.

Another important point is the greater diminution of strength of aluminium alloys with temperature increase for connecting-rods become heated up, due to conduction and radiation during the running of the engine.

**Aluminium Automobile Body Work.**

The use of sheet aluminium for motor body bonnets, panels, and general body work is rapidly extending, as its use not only involves less weight, but the material is much easier to work.

Aluminium matting, running boards, beading and piping, number plates and wheel discs, etc., are now common in automobile practice.

FIG. 28.—CAST ALUMINIUM IN AUTOMOBILE BODY.

Limousine and other types of automobile body are now made up from aluminium castings. The advantages of employing cast aluminium sections are that the body is more rigid than if of sheet design, whilst the elimination of bracing required in the latter case allows the cast body to be as light, or even lighter; warping and buckling cannot readily occur, and it has been found that cast aluminium bodies can withstand to a remarkable degree the stresses produced by road shocks, etc.

A good example of this class of work in shown in Fig. 28,

which illustrates the method of assembling the sections to form the body of a Pierce-Arrow car. These castings are of $\frac{1}{8}$ inch thickness throughout the greater part. There is no wooden framework, the only wood employed in the construction being for the sills of the doors and windows, partitions, floor, and driver's seat.

The joints are all arranged to come at the lines of the body, and these are cast with ribs, so that when the body is assembled it has the appearance of one piece, with no open joints.

The sections are fastened together by riveting, and the upholstery is of the detachable type.

## Air Ministry Specification for Aluminium Alloy Castings.

(Suitable for Crank Cases and General Use.)

*The specific gravity of this alloy is* 3·0.

1. Quality of Material.—The aluminium used for making this alloy is to assay not less than 98 per cent.

The copper used for making this alloy is to assay not less than 99·3 per cent.

The zinc used for making this alloy is to be of the best quality.

The alloy is to consist of—

Zinc, not less than 12·5 per cent. or more than 14·5 per cent.
Copper „ „ 2·5 „ „ „ 3·0 „
Aluminium, remainder.

Impurities—

Lead, not more than 0·1 per cent.
Silicon „ „ 1·0 „
Iron „ „ 1·0 „

2. Chemical Tests.—Samples of the aluminium, zinc, and copper and of the castings, may be selected by the Inspector at the Contractor's expense for chemical analysis, which will be made at the expense of the Government. Should the analysis show that the composition of the material is not within the limits specified in Clause 1, the articles represented by the samples may be rejected.

3. Dimensions.—The castings are to be accurately in accordance with the drawings, and sufficient allowance is to be made to enable them to be machined where required to the finished dimensions without leaving witness of the cast surface.

4. Freedom from Defect.—The castings are to be clean, sound, and free from blow-holes. They are to be capable of being machined satisfactorily and taking a good finish.

*Patching.*—No patching, plugging, or welding will be allowed unless previous permission in writing has been obtained from the Inspector; such permission will only be given when the defects to be patched are small and do not affect the strength of the casting.

Any casting may be rejected for faults of manufacture or incorrectness of dimensions at any time, notwithstanding that it has been previously passed as complying with this specification by analysis and physical tests.

5. MECHANICAL TESTS.—The metal is to comply with the following tests, which are to be carried out by the Contractor at his works in the presence of the Inspector and to his satisfaction.

*Tensile Test.*—Test pieces turned to the dimensions of British Standard test piece, from sample pieces cast as specified in Clause 6, must give the following results—

Ultimate strength not less than 11 tons per square inch.
Elongation „ „ 4 per cent.

The test pieces are not to be annealed, hammered, or otherwise treated before they are tested.

The ultimate strength of this alloy should be over 12 tons per square inch, and the alloy will not be considered first rate till this strength is attained.

6. PROVISION OF TEST SAMPLES.—At least one sample is to be cast to represent each crank case or other large casting. The number of samples for small castings is to be settled by the Inspector, so that all the alloy used is tested. The samples are to be cast from the same ladle as the castings and are to be poured first.

The samples are to be 1 inch in diameter and from 7 inches to 9 inches long. They are to be cast in iron chills which have been heated before they are filled. The bottom of the chill is to be closed with a clay or sand plug, not with a metal end.

7. MARKING.—All castings accepted by the Inspector are to be marked as he may direct.

8. REJECTIONS.—All castings rejected by the Inspector are to be broken up or marked for identification to the satisfaction of the Inspector, and are not to be tendered again to any Government Department without giving written information to that Department or their Inspector concerning the previous rejection.

9. INSPECTION.—The Contractor is not to supply any castings which have been previously rejected by any Government Inspection Department without giving written information to the Inspector about the previous rejection. The Inspector is to have free access to the works of the Contractor at all reasonable times; he is to be at liberty to inspect the manufacture at any stage and to reject any material that does not conform to the terms of this specification.

10. FACILITIES.—The contractor is to supply the material required for testing without additional charge, and at his own cost furnish and prepare the necessary test pieces, and supply labour and appliances for such inspection and testing as may be carried out on his premises in accordance with this specification. Failing approved facilities at his own works for making the prescribed tests, the Contractor is to bear the cost of carrying out the tests elsewhere.

## SPECIFICATION FOR 12 PER CENT. COPPER-ALUMINIUM ALLOY CASTINGS.

*The specific gravity of this alloy is between* 2·83 *and* 2·94.

1. QUALITY OF MATERIAL.—(*a*) The aluminium used for making this alloy is to assay not less than 98 per cent.

(*b*) The copper used for making this alloy is to assay not less than 99·3 per cent.

(c) The alloy is to consist of—

Copper, not less than 11 per cent. or more than 13 per cent.
Aluminium, remainder.

(d) Impurities—

| | | | | |
|---|---|---|---|---|
| Zinc, | not more | than | 0·1 | per cent. |
| Lead | „ | „ | 0·1 | „ |
| Silicon | „ | „ | 1·0 | „ |
| Iron | „ | „ | 1·0 | „ |

6. Mechanical Tests.—(a) The metal is to comply with the following tests, which are to be carried out in the presence of the Inspector and to his satisfaction.

(b) *Tensile Tests.*—Test pieces turned to the dimensions of British Standard test piece, from sample pieces cast as specified in Clause 6 (same as that of above specification), must give the following result—

Ultimate stress not less than 9 tons per square inch.

(c) The test pieces are not to be annealed, hammered, or otherwise treated before they are tested.

## Specification for Aluminium Alloy Castings.

*The specific gravity of this alloy is* 2·95.

1. Quality of Material.—(a) The aluminium used for making this alloy is to assay not less than 98 per cent.

(b) The copper used for making this alloy is to assay not less than 99·3 per cent.

(c) The alloy is to consist of—

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Copper, | not less | than | 9·0 | per cent. | or more | than | 11·0 per cent. |
| Tin, | „ | „ | 0·5 | „ | .. | „ | 1·5 „ |

Aluminium, remainder.

(d) Impurities—

| | | | | |
|---|---|---|---|---|
| Lead, | not more | than | 0·1 | per cent. |
| Silicon | „ | „ | 1·0 | „ |
| Iron | „ | „ | 1·0 | „ |

2. Chemical Tests.—Samples of the aluminium, tin, and copper, and of the castings, may be selected by the Inspector at the Contractor's expense for chemical analysis, which will be made at the expense of the Government. Should the analysis show that the composition of the material is not within the limits specified in Clause 1, the articles represented by the samples may be rejected.

5. Mechanical Tests.—(a) The metal is to comply with the following tests, which are to be carried out in the presence of the Inspector and to his satisfaction.

(b) *Tensile Test.*—Test pieces turned to the dimensions of British Standard test piece, from sample pieces cast as specified in Clause 6 (same as that of above specification), must give the following result—

Ultimate strength not less than 9 tons per square inch.

(c) The test pieces are not to be annealed, hammered, or otherwise treated before they are tested.

7. Hydraulic Test.—(a) All cylinder castings and others which are required to be tight are to be tested for porosity by means of water, methylated spirits, or petrol. The test is to be carried out in an approved manner to the satisfaction of the Inspector.

(b) Castings which have been tested are to be marked to show the

result of this test as the Inspector may direct. All castings which in the opinion of the Inspector are too porous for use will be rejected. Castings which are only slightly porous will be accepted subject to their proving tight after subsequent doping.

8. Doping.—(a) Doping may be carried out by the Contractor or at the machine shop, as may be arranged. If the Contractor dopes the castings he is to do so in an approved manner to the satisfaction of the Inspector.

## Specification for 7 : 1 : Aluminium Alloy Castings.

*The specific gravity of this alloy is between* 2·87 *and* 2·93.

1. Quality of Material.—(a) The aluminium used for making this alloy is to assay not less than 98 per cent.

(b) The copper used for making this alloy is to assay not less than 99·3 per cent.

(c) The alloy is to consist of—

| | | | | | | |
|---|---|---|---|---|---|---|
| Copper, | not less than | 6·0 | per cent. | or more than | 8·0 | per cent. |
| Tin | ,, ,, | 0·5 | ,, | ,, ,, | 2·0 | ,, |
| Aluminium, remainder. | | | | | | |

(d) Impurities—

| | | | |
|---|---|---|---|
| Lead, | not more than | 0·1 | per cent. |
| Zinc | ,, ,, | 1·0 | ,, |
| Silicon | ,, ,, | 1·0 | ,, |
| Iron | ,, ,, | 1·0 | ,, |

5. Mechanical Tests.—(a) The metal is to comply with the following tests, which are to be carried out in the presence of the Inspector and to his satisfaction.

(b) *Tensile Test.*—Test pieces turned to the dimensions of British Standard test piece, from sample pieces cast as specified in Clause 6 (same as that of above specification), must give the following result—

Ultimate stress not less than 8 tons per square inch.

(c) The test pieces are not to be annealed, hammered, or otherwise treated before they are tested.

## CHAPTER II

# COPPER AND ITS ALLOYS

## COPPER

Copper is extensively employed in engineering work, both in the element form and alloyed with other metals as of gun-metal, brass, bronze, etc.

It is a very malleable and ductile metal of a reddish colour. Its *specific gravity* is 8·90, on the average, at 0° C.; this corresponds to a weight of 0·32117 pounds per cubic inch.

The *melting point* of copper is 1083° C. (1981° F.), and in the molten state the metal has a sea-green colour; it boils at a temperature of 2310° C. (4190 F.), and when heated to a higher temperature vaporizes and burns with a green flame. Molten copper readily absorbs oxygen, hydrogen, carbon-monoxide, and sulphur dioxide, and on cooling the occluded gases are liberated, leaving the mass porous; for this reason it is both difficult to cast and to weld copper.

The *annealing temperature* of copper is about 750° C. (1380° F.).

The *specific heat* is 0·094 (water = 1).

Copper has a high conductivity, both thermally and electrically, being the best of all commercial metals in these respects.

Its *thermal conductivity* is 73·6 (silver = 100).

Its *electrical conductivity* is 97·5 (silver = 100).

The *coefficient of linear expansion* is 0·0000170 per °C., or 0·0000093 per ° F.

The specific resistance in microhms per centimetre cube at 68° F. (20° C.) is—

(*a*) Hard .. .. .. 1·760
(*b*) Soft .. .. .. 1·724

The corresponding values at 32° F. (0° C.) are—

(*a*) Hard .. .. .. 1·620
(*b*) Soft .. .. .. 1·587

The resistance of a copper conductor 100 feet long by 1 square inch cross section is—

(*a*) Hard .. .. .. ·008316

(*b*) Soft .. .. .. ·008143

The coefficient of increase of resistance per °C. is 0·00428

" " " " °F. is 0·0024

Copper occurs commercially in three principal grades, namely, the *Electrolytic*, the *Lake*, and the *Cast* grades.

The former is the purest form of copper and it is obtained by the process of electrolysis, the metal being about 99·88 per cent. pure. Wire bars of electrolytic copper are obtained by melting down cathode copper in a furnace and casting to the desired form for drawing or rolling.

The impurities present in this form of copper include very small percentages of sulphur, nickel, lead, arsenic, antimony, bismuth, tellurium, selenium, iron, aluminium, and phosphorus.

*Casting copper*, in the better grades, is about 99 per cent. pure, and is derived from (*a*) fire-refined copper from the ore; (*b*) copper electrolytically produced by deposition from impure liquors; and (*c*) copper reclaimed from secondary sources.

Casting copper is employed chiefly for foundry purposes.

**Copper Castings.**

The difficulty in casting copper is similar to that experienced in the welding of this metal, and is due to the affinity of the molten metal for oxygen, which renders the castings porous. Copper castings may be obtained which are quite homogeneous by the addition of boron to the melted metal, in the form of 1 per cent. of boron sub-oxide flux (which is equivalent to from 0·08 to 0·1 per cent. of boron sub-oxide).*

Another method for making copper castings† of high electrical conductivity is to melt the metal under a cover of

* See also p. 82.

† Copper castings are used for electrical and thermal purposes on account of their high conductivity.

charcoal and common salt. When thoroughly fluid, about 2 ounces of stick magnesium is added to every 100 pounds of copper, and is held beneath the surface until reaction ceases. The metal should be stirred for about 5 minutes with a plumbago stirrer and re-heated before pouring.

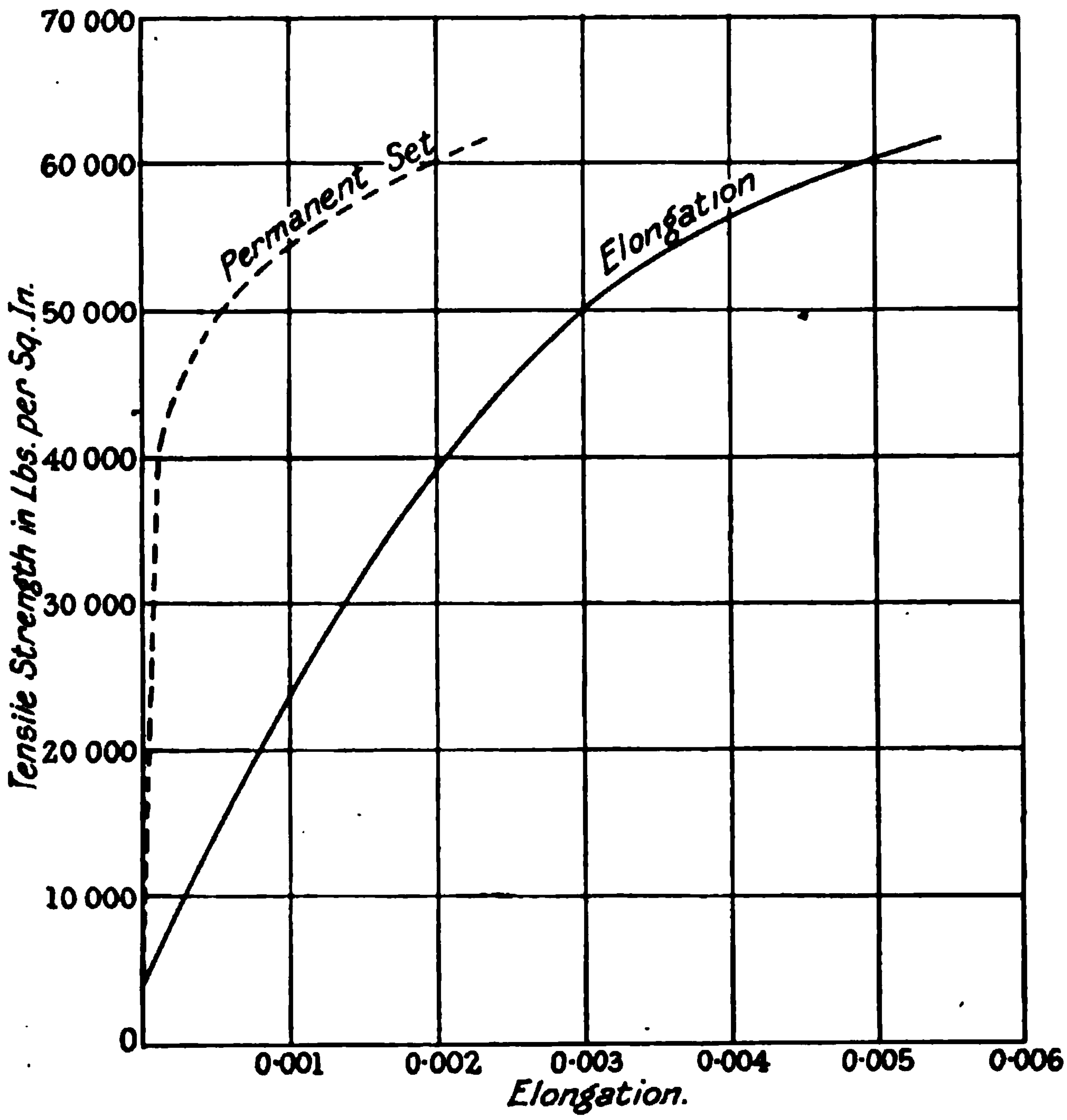



FIG. 29.—STRESS-STRAIN CURVES FOR COPPER WIRE.

**Mechanical Properties of Copper.**

The tensile strength of copper varies considerably with its treatment and mode of derivation.

In the cast state the tensile strength varies from 8½ to 12 tons per square inch, whilst in the hammered or sheet form it varies from 12 to 16 tons per square inch.

Copper wire can be drawn, having a tensile strength varying from about 18 to 30 tons per square inch ; the tensile strength also increases as the diameter decreases, from about 20

to 25 tons per square inch for the larger diameters, up to about 30 tons per square inch for the smallest diameters.

The strength of annealed copper wire is about 14 to 16 tons per square inch for the larger sizes and about 15 to 18 tons per square inch for the smaller sizes.

The following values represent some of the more reliable results for copper in different conditions.

## TABLE XXX.

### Properties of Copper.

| *Condition.* | *Tensile strength, tons per sq. inch.* | *Elongation per cent.* | *Reduction of area, per cent.* |
|---|---|---|---|
| Copper rods for fire-box stays .. | 14·9 | 46·5 on 8ins | 66·1 |
| Annealed ditto. .. .. .. | 13·4 | 52 on 8 ins. | 67 |
| Copper plates for fire-boxes .. | 13·5–14·9 | 43-30 on 8 ins. | 60–40 |
| Forged copper .. .. .. | 15·2 | — | — |
| ,, ,, with 0·015 phosphorus | 17·0 | — | — |
| ,, ,, ,, 0·02 ,, | 20·1 | — | — |
| ,, ,, ,, 0·03 ,, | 21·4 | — | — |
| ,, ,, ,, 0·04 ,, | 22·3 | — | — |
| Ingot copper .. .. .. | 11·6–13·3 | — | — |
| Cast ,, .. .. .. | 6·5–9·2 | — | — |
| Rolled ,, .. .. .. | 12·9–14·3 | — | 30–45 |
| ,, ,, ½ inch thick .. .. | 13·3–14·2 | 43–20 on 8 ins. | — |

There is no true or elastic limit yield point in the case of copper, the stress-strain diagram consisting of a curved line somewhat resembling that for cast iron.

Fig. 29 shows the stress-strain curve for hard-drawn copper wire, and it will be seen therefrom that only a small portion of the curve is approximately straight.

The strength of copper wire can be expressed in terms of the strength $P$ in pounds, and the diameter $d$ in inches, in the following manner (Unwin)—

Annealed .. .. $P = 262d + 25{,}000d^2$
Half Hard .. .. $P = 850d + 31{,}400d^2$
Hard Drawn .. .. $P = 788d + 39{,}800d^2$

For English hard-drawn telegraph copper wire the weight in pounds is given by $P = 3{\cdot}955\sqrt{W} + 2{\cdot}753\ W$ pounds, where $P$ has the same value as before.

The "Johnson" elastic limit, which is defined as the point on the stress-strain curve at which the natural tangent is 1·5 times the tangent of the angle of the straight or linear portion of the curve with respect to the axis of ordinates, is about 44,000 pounds (or 19·65 tons) per square inch, that is to say, 72 per cent. of the tensile strength (61,400 pounds or 27·4 tons per square inch), and the modulus of elasticity is 17,500,000 pounds or 7800 tons per square inch.

The elongation on 30 inches at rupture was 1·3 per cent.

The modulus of elasticity for cast copper is given by Thurston as 4460 to 6700 tons per square inch; that of hard-drawn wire as 7650, and of annealed wire as 6680 to 7650 tons per square inch.

The coefficient of bending strength is from 8·9 to 17·8 tons per square inch for cast copper and up to 26·7 for rolled copper.

The tensile strength of copper diminishes with increase in temperature, and for this reason it is necessary to employ the strength values at the real working temperatures in design work.

The following results are given by Unwin for the strengths of rolled copper at different temperatures, the sizes of the test piece in each case being about 0·313 inches in diameter.

TABLE XXXI.

STRENGTH OF COPPER AT DIFFERENT TEMPERATURES.

(Unwin.)

| *Temperature ° F.* | *Tensile strength tons per sq. inch* | *Elongation. per cent. on 2 inches.* | *Contraction of area.* |
|---|---|---|---|
| Atmospheric | 17·84 | 10·0 | 49·2 |
| 210° | 17·41 | 9·0 | 49·7 |
| 300° | 16·43 | 8·0 | 49·5 |
| 410° | 15·95 | 9·0 | 50·6 |
| 500° | 15·09 | 7·0 | 37·7 |
| 600° | 14·30 | 4·0 | 22·2 |
| 600° | 14·18 | 5·0 | 17·4 |
| 640° | 13·70 | 4·5 | 17·1 |

**Impurities in Copper.**

The impurities which occur in commercial copper comprise arsenic, antimony, bismuth, iron (traces), lead, nickel, oxygen, sulphur, and tellurium; occasionally tin, zinc, or silver is present in exceedingly small quantities.

Oxygen, in the form of cuprous oxide, has the effect of causing brittleness when present in any appreciable quantity.

Arsenic increases the hardness and strength, and when present in moderate amounts increases the ductility; for this reason it is usual to specify from 0·3 to 0·5 per cent. of arsenic for fire-boxes, etc.

The following is a typical fire-box copper analysis—

| | *Per cent.* |
|---|---|
| Copper | 99·195 |
| Antimony | ·006 |
| Arsenic | ·534 |
| Bismuth | ·007 |
| Iron | ·022 |
| Lead | ·051 |
| Nickel | ·094 |
| Silver | ·015 |
| Sulphur | trace |
| Oxygen (combined) | ·076 |

The corresponding strength properties were as follows—

| | | |
|---|---|---|
| Tensile strength | 15·06 | tons per square inch |
| Contraction of area | 50·7 | per cent |
| Elongation in 8 inches | 38·5 | " |

Bismuth is probably the most deleterious element in copper, as it reduces the tensile strength and renders the metal red-short.

Lead has a softening effect upon copper, but also renders it red-short.

Sulphur and tellurium tend to embrittle the metal.

Nickel in the usual quantities found has no deleterious action.

The properties of copper containing different amounts of bismuth and arsenic, at various temperatures, are shown in Fig. 30.*

* "An Introduction to Metallurgy," Sir Roberts-Austen. Also see Second Report to Alloy's Research Committee. *Proc. Inst. Mech. Engrs.*, 1893.


FIG. 30.—SHOWING THE EFFECT OF ARSENIC AND BISMUTH ON THE STRENGTH OF COPPER AT DIFFERENT TEMPERATURES.

**Copper Alloys.**

The theory of the formation and constitution of alloys has been briefly considered in Chapter IV, Vol. I of this work, and some idea of the underlying principles will have been gathered therefrom. The present considerations deal solely with the compositions, mechanical and physical properties, and industrial uses of the alloys.

Copper is capable of forming a very useful series of alloys, with metals such as tin, zinc, iron, aluminium, and others, to which definite names have been given as follows—

| | |
|---|---|
| *Brasses* .. .. | Alloys of copper and zinc, sometimes with small amounts of lead and tin. |
| *Gun-metals* .. .. | Alloys of copper and tin. |
| *Bronzes* .. .. | Alloys of copper, tin, and small amounts of other metals. |
| *Aluminium bronzes* | Alloys of copper and aluminium. |
| *Phosphor bronzes* .. | Alloys of copper, tin, and small amounts of phosphorus. |
| *Manganese bronzes*.. | Alloys of ordinary bronzes with ferro-manganese. |
| *Silicon bronzes* .. | Alloys of copper and silicon. |
| *Delta metals* .. | Alloys of copper, zinc, and iron. |
| *Bell metals* .. | Alloys of copper and tin, often with iron, lead, and zinc. |
| *German silvers* .. | Alloys of copper and nickel, sometimes with tin or zinc. |
| *Monel metal* .. | Alloys of copper, nickel, and iron. |
| *Bearing metal* .. | Alloys of copper, tin, lead, zinc, iron, and antimony (the first three metals alone, with or without each or any of the last three). |
| *Silver solder* .. | Alloys of copper, silver, and (*or*) zinc. |
| *Brazing metal or Spelter* .. .. | Alloys of copper, zinc, tin, or nickel. |
| *Cupro-Nickel or Constantan* .. .. | Alloys of copper and nickel. |

The above are the more important of the copper alloys, but there is a large number of alloys, many of which are often known under trade names, made for particular purposes, outside of the scope of the present considerations.

A large amount of valuable work in connexion with the subject of alloys of commercial importance has been done by different authorities, to the results of which the reader is referred for fuller information than is given here. Amongst the more important researches are those of the Alloys Research

Committee of the Institution of Mechanical Engineers, the United States Test Board (under the chairmanship of Prof. R. H. Thurston), and the Institute of Metals.

## BRASSES

The principal constituents of all brasses are copper and zinc; lead, tin, and iron are sometimes present in small

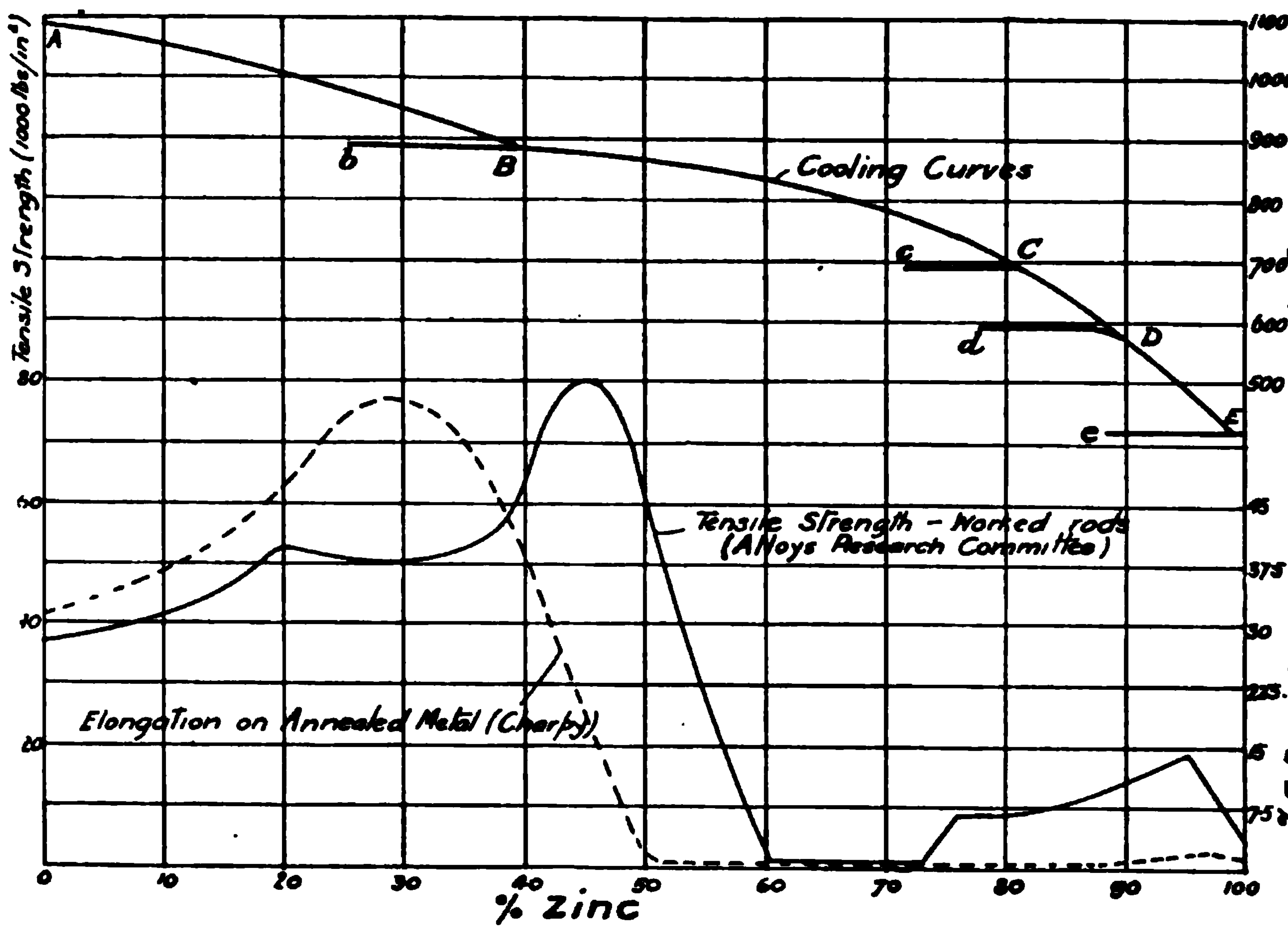



FIG. 31.—COOLING AND STRENGTH PROPERTY CURVES FOR COPPER-ZINC ALLOYS OR BRASSES.

quantities. Fig. 31* shows the general properties of the copper-zinc alloys.

Ordinary cast brass contains from 66 to 70 per cent. of copper and from 34 to 30 per cent. of zinc, the tensile strength varying from 14 to 17 tons per square inch, with a yield

* Fourth Report to the Alloys Research Committee." *Proc. Inst. Mech. Engrs.*, 1897.

point of from 5 to 7 tons per square inch. Common brass for cheap brass work usually contains more zinc (from 35 to 50 per cent.) and is inferior in strength properties.

**Ductile Brasses.**

Brasses containing upwards of 65 per cent. of copper are ductile and malleable at ordinary temperatures, but the constituents must be pure and the metal properly annealed before and during working; the ordinary annealing temperatures of brass are from 650° C. to 700° C. The melting points of the more common brasses will be found in Table 37 on p. 95.

The above ductile brasses can be rolled or drawn into wires, tubes, rods, sheets, and similar shapes, but although lead may be present without detriment in metal for sheets, it is injurious for wire purposes.

**Forgeable Brasses.**

Brasses containing from 58 to 62 per cent. of copper, with the balance of zinc, may be worked in the hot state at temperatures of from 600° to 750° C., the melting point being about 880° C. to 900° C. This grade of brass may be drop-forged and stamped; it is also used for bolts, nuts, ships' fittings, and sheathing plates. The effect of quenching these brasses from 750° C. to 800° C. is to make them harder, stronger, but less ductile than if allowed to cool slowly. *Muntz metal* is one of these forgeable brasses, having a composition consisting of 60 per cent. copper and 40 per cent. zinc. They should not be worked at temperatures much below 600° C., as cracking is liable to result, but if annealed at 200° C. to 300° C. beforehand, this risk is lessened.

The following are the average strength properties of this and other grades of brass, but it should be pointed out that the strength and hardness both vary considerably with the purity of the constituents and the nature of the mechanical and heat treatment.

## TABLE XXXII.

### Properties of Brasses.

| *Condition.* | *Composition.* | | *Yield point, tons per sq. inch.* | *Tensile strength, tons per sq. inch.* | *Elongation per cent. on 2 inches.* | *Brinell hardness No.* |
|---|---|---|---|---|---|---|
| | *Copper.* | *Zinc.* | | | | |
| Forgeable brass (cast and annealed) .. .. .. | 60 | 40 | 18 | 25 | 35 | 85 |
| Forgeable brass (drawn rod) | 60 | 40 | 28 | 32 | 20–30 | 140 |
| Ordinary cast brass .. | 66 | 34 | 6 | 14 | 40 | — |
| Ductile brass (annealed after rolling) .. .. .. | 70 | 30 | 10 | 23 | 70 | 120 |
| Ductile brass— | | | | | | |
| Reduced 10 per cent. by rolling | 70 | 30 | 19·5 | 28·1 | 40·5 | 87 |
| " 20 " " | 70 | 30 | 26·0 | 32·8 | 29·3 | 116 |
| " 30 " " | 70 | 30 | 29·8 | 36·7 | 23·2 | 139 |
| " 40 " " | 70 | 30 | 33·5 | 40·0 | 19·1 | 154 |
| " 50 " " | 70 | 30 | 36·3 | 42·7 | 16·3 | 166 |
| " 60 " " | 70 | 30 | 39·2 | 44·8 | 14·5 | 176 |
| " 70 " " | 70 | 30 | 41·5 | 46·2 | 12·9 | 184 |

**Naval Brass.**

This brass resembles Muntz metal in composition, but also contains from 1 to 1½ per cent. of tin.

The effect of the tin is to increase the strength and hardness, but to lessen the elongation (or ductility), and also to render the metal more non-corrodible. A typical composition for naval brass is as follows: Copper, 62 per cent.; zinc, 37 per cent.; tin, 1 per cent.

## TABLE XXXIII.

### Compositions of Various Grades of Rolled Brasses, Etc.

(Kent.)

| *Trade Name.* | *Composition.* | | | | |
|---|---|---|---|---|---|
| | *Copper.* | *Zinc.* | *Tin.* | *Lead.* | *Nickel.* |
| Common high brass .. | 61·5 | 38·5 | — | — | — |
| Yellow metal .. .. | 60 | 40 | — | — | — |
| Cartridge brass .. .. | 66⅔ | 33⅓ | — | — | — |
| Low brass .. .. .. | 80 | 20 | — | — | — |
| Clock brass .. .. .. | 60 | 40 | — | 1½ | — |
| Drill rod .. .. .. | 60 | 40 | — | 1½–2 | — |
| Spring brass .. .. | 66⅔ | 33⅓ | 1½ | — | — |
| German silver (18 per ecnt.) | 61½ | 20½ | — | — | 18 |
| Naval brass .. .. | 62 | 37 | 1 | — | — |

**Effect of Additional Elements upon Brass.**

When *tin* up to 2 per cent. is present it has the effect stated above, but over 4 per cent. of tin tends to produce brittleness. Table 34 shows the effect of tin in various quantities up to 25 per cent. upon the copper-zinc, or brass series of alloys. The highest tensile strengths, it will be observed, occur when from 2 to 5 per cent. of tin is present. These alloys really belong to the gun-metal or bronze series.

The effect of *lead* (from 1 to 3 per cent.) is to render the metal better for machining, but it reduces the strength and hardness, increases the corrodibility, and is apt to segregate in the portions of the castings that solidify last in cooling.

*Iron*, when present in from 1 to 3 per cent., increases the strength and hardness considerably; the well-known *Delta metals* are brasses containing iron and manufactured by a special process.

TABLE XXXIV.

STRENGTH OF COPPER-ZINC-TIN ALLOYS.

(U.S. Government Tests.)

| *Composition, per cent.* | | | *Tensile strength, tons per sq. inch.* | *Composition, per cent.* | | | *Tensile strength, tons per sq. inch.* | *Composition, per cent.* | | | *Tensile strength, tons per sq. inch.* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Copper* | *Zinc* | *Tin* | | *Copper* | *Zinc.* | *Tin* | | *Copper* | *Zinc* | *Tin* | |
| 45 | 50 | 5 | 6·70 | 60 | 20 | 20 | 4·65 | 75 | 20 | 5 | 20·40 |
| 50 | 45 | 5 | 22·35 | 65 | 30 | 5 | 22·35 | 75 | 15 | 10 | 20·40 |
| 50 | 40 | 10 | 6·70 | 65 | 25 | 10 | 18·76 | 75 | 10 | 15 | 19·20 |
| 55 | 43 | 2 | 28·04 | 65 | 20 | 15 | 13·40 | 75 | 5 | 20 | 18·30 |
| 55 | 40 | 5 | 27·70 | 65 | 15 | 20 | 8·04 | 80 | 15 | 5 | 20·40 |
| 55 | 35 | 10 | 14·50 | 65 | 10 | 25 | 5·36 | 80 | 10 | 10 | 20·40 |
| 55 | 30 | 15 | 6·70 | 70 | 25 | 5 | 20·10 | 80 | 5 | 15 | 20·95 |
| 60 | 37 | 3 | 26·80 | 70 | 20 | 10 | 19·65 | 85 | 10 | 5 | 19·20 |
| 60 | 35 | 5 | 23·46 | 70 | 15 | 15 | 16·52 | 85 | 5 | 10 | 20·70 |
| 60 | 30 | 10 | 17·88 | 70 | 10 | 20 | 13·40 | 90 | 5 | 5 | 18·75 |

**General Properties of Copper-Zinc Alloys.***

Table 35 gives the properties of alloys containing from 0 to 55 per cent. of zinc. In reference to the low zinc alloys, it has been found that when less than 15 per cent. of zinc

* Also see Fig. 31, p. 90.

is present the castings are porous or full of blow-holes and the metal shows signs of oxidation, due no doubt to the occlusion of the gases by the large copper content.

Between 17 and 30 per cent. of zinc content, the alloys are very similar in their properties, and in their colour, although the ductility decreases as the zinc content increases further.

## TABLE XXXV.

### STRENGTH OF COPPER-ZINC ALLOYS.

(U.S. Government Tests.)

| *Composition.* | | *Yield point, tons per sq. inch.* | *Tensile strength, tons per sq. inch.* | *Elongation per cent.* | *Compressive strength, tons per sq. inch.* |
|---|---|---|---|---|---|
| *Copper.* | *Zinc.* | | | | |
| 100 | 0 | 6·25 | 12·05 | 7 | 18·30 |
| 95 | 5 | 5·36 | 12·50 | 12 | 12·50 |
| 90 | 10 | 4·46 | 13·40 | 18 | 12·96 |
| 85 | 15 | 4·02 | 14·30 | 25 | 14·74 |
| 80 | 20 | 3·57 | 15·19 | 33 | 17·41 |
| 75 | 25 | 4·02 | 16·62 | 38 | 20·58 |
| 70 | 30 | 4·46 | 18·31 | 38 | 24·14 |
| 65 | 35 | 5·81 | 20·58 | 33 | 28·15 |
| 60 | 40 | 7·70 | 21·90 | 19 | 33·20 |
| 55 | 45 | 8·84 | 19·65 | 10 | 40·20 |
| 50 | 50 | 10·71 | 13·40 | 4 | 51·9 |
| 45 | 55 | 6·25 | 6·25 | — | 56·3 |

Alloys containing from 30 to 40 per cent. of zinc show a progressive increase in strength and decrease of ductility.

Alloys containing less than 55 per cent. of zinc are all yellow metals; beyond 55 per cent. the colour changes to white, and the metal becomes weak and brittle. Between 70 per cent. and 100 per cent. zinc content the colour is a bluish-grey, and the brittleness decreases and the strength tends to increase.

## TABLE XXXVI.

### Composition of Alloys for Casting Purposes.

| *Material.* | *Percentage Composition.* Copper. | Tin. | Zinc. | Iron (max.). | Lead (max.). | *Miscellaneous.* |
|---|---|---|---|---|---|---|
| (*A*) | | | | | | |
| Commercial brass | 64–68 | — | 32–34 | 2·0 | 3·0 | — |
| Cast naval brass | 59–63 | 0·5–1·5 | Remainder | 0·06 | 0·6 | — |
| Copper .. .. | 99·8† | — | — | — | — | To be free from sulphur & other impurities. |
| Zinc, rolled plates | — | — | 98·5† | 0·08 | — | — |
| Tin .. .. | — | 99·6† | — | — | — | — |
| Lead (1) .. | — | — | — | — | 99·5† | — |
| ,, (2) .. | — | — | — | — | 97·5† | — |
| Muntz metal .. | 59–62 | — | 39–41 | — | 0·6 | — |
| Brazing metal | 84–86 | — | Remainder | 0·06 | 0·3 | — |
| Gun bronze .. | 87–89 | 9–11 | 1–3 | 0·06 | 0·2 | — |
| Journal bronze | 82–84 | 12·5-14·5 | 2·5–4·5 | 0·06 | 1·0 | — |
| Valve bronze .. | 87 | 7 | Remainder | 0·06 | 1·0 | — |
| Manganese bronze* .. | 57–60 | 0·75 | 37–40 | 1·0 | — | Aluminium, 0·5; Manganese, 0·3 |
| Phosphor bronze | 80–90 | 6–8 | Remainder | 0·06 | 0·2 | Phosphorus 0·3 |
| | Remainder | — | — | 6·5 | — | Nickel, 60 (min.); Aluminium, 0·5 |
| (*B*) | | | | | | |
| Common brass castings .. | 84 | 10·5 | 5·5 | — | — | — |
| Brass to be rolled | 73·5 | 3·5 | 13·0 | — | — | — |
| Gun metal .. | 88 | 12 | — | — | — | — |
| Bronze statuary | 91·4 | 1·7 | 5·53 | — | 1·37 | — |
| Britannia metal | 0·2 | 90 | — | — | — | Antimony, 9·2 |
| Bell metal .. | 80 | 20 | — | — | — | — |
| Spelter .. | 50 | — | 50 | — | — | — |
| Type metal .. | — | — | — | — | 80–90 | Antimony, 10-20 |
| White metal (medium) .. | 6 | — | — | — | 82 | Antimony, 12 |
| Brazing metal | 85 | — | 15 | — | — | — |
| Tobin bronze.. | 59–63 | 0·5–1·5 | Remainder | — | — | — |
| Speculum metal | 66–68 | 34–32 | — | — | — | — |

## TABLE XXXVII.

### Melting Points of Copper-Zinc Alloys.‡

| *Percentage Composition, by weight.* Copper. | Zinc. | *Melting Point, ° Centigrade.* |
|---|---|---|
| 95 | 5 | 1070 |
| 90 | 10 | 1055 |
| 85 | 15 | 1025 |
| 80 | 20 | 1000 |
| 75 | 25 | 980 |
| 70 | 30 | 940 |
| 65 | 35 | 915 |
| 60 | 40 | 890 |

* Approximate figures ; the values for lead, aluminium and iron represent the maximum permissible quantities.

† Minimum

‡ "The Approximate Melting Points of Some Commercial Copper Alloys," H. W. Gillett and A. B Norton. Bureau of Mines, Washington, D.C., 1913.

## TABLE XXXVIII.

### Specific Gravities of Copper-Zinc Alloys.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Copper, per cent | 100 | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | 0 |
| Zinc, per cent. | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| Specific Gravity | 8·80 | 8·72 | 8·60 | 8·40 | 8·36 | 8·20 | 8·00 | 7·72 | 7·40 | 7·20 | 7·14 |

## International Aircraft Standard Specification.

### 3N7—*Specifications for Seamless Brass Tubes.*

1. General.—The general specifications, 1G1, shall form, according to their applicability, a part of these specifications.

2. Use.—This tubing is resistant to the corrosive action of salt water salt air, and gases.

3. Material.—(*a*) The brass shall have the following composition—

| | *Per cent.* |
|---|---|
| Copper .. .. .. | 79·00–82·00 |
| Lead, maximum .. .. | ·20 |
| Iron, maximum .. .. | ·10 |
| Zinc .. .. .. .. | Remainder |

(*b*) Samples for analysis may consist of turnings taken from the end of the tube or of drillings. Points from which drillings are taken must be distributed around the surface of the tube so as to yield a representative sample of the tube wall.

4. Manufacture.—(*a*) The brass shall be made from lake or electrolytic copper conforming to the I.A.S.B. specification 2N2 and from B or C grade spelter conforming to I.A.S.B. specification 2N3.

(*b*) No scrap shall be used other than that produced in the manufacturer's own plants and of the same composition as the material specified.

(*c*) Tubing shall be semi-annealed unless otherwise specified.

(*d*) Any sheet may be rejected because of injurious defects or faults in manufacture at any time, notwithstanding that it has previously passed inspection; it shall be returned to the manufacturer at the latter's expense. This clause shall not be taken to apply to materials fabricated after export.

5. Workmanship and Finish.—The tubing shall be clean, smooth, and free from all injurious defects, both inside and outside.

6. Physical Properties and Tests.—(*a*) *Flattening Test.*—A piece of tube, 2 diameters in length, shall be flattened with a hammer until it passes freely through a micrometer caliper set at three times the thickness of the tube wall. The tube must stand this test without showing cracks or other defects.

(*b*) *Expanding Test.*—A pin with a taper of 1 in 8 shall be driven into one end of the tube until the tube's diameter is increased by one-sixth. The tube must stand this test without showing cracks, splits, or other defects.

(*c*) *Hydrostatic Pressure Test.*—Each tube shall be subjected to a hydrostatic pressure which will develop a tensile stress of 7000 pounds per square inch (4·92 kg./mm.$^2$) in the tube, but in no case shall a test pressure of more than 1000 pounds per square inch (0·703 kg./mm.$^2$)

be required. Each tube must withstand this test without cracks, flaws, leaks, or other defects such as bulging.*

7. SELECTION OF TEST SPECIMENS.—(*a*) Each tube shall be subjected to a hydrostatic test. One tube from each lot of 100 or less shall be subjected to a flattening and to an expanding test.

(*b*) If any tube fails to pass the flattening or the expanding test, two more tubes representing the same lot shall be subjected to both tests. If either of these tubes fail in either test the lot which they represent shall be rejected.

(*c*) Any tube failing to meet the hydrostatic test shall be rejected.

8. DIMENSIONS AND TOLERANCES.—(*a*) *Tolerances.*—The following tolerances shall be allowed on wall thickness and outside diameter—

TOLERANCES FOR OUTSIDE DIAMETER AND WALL THICKNESS.

| *Outside diameter.* | *Tolerances on outside diameter.* | *Wall thickness.* | *Wall thickness tolerance.* |
|---|---|---|---|
| *Inches.* | *Inch.* | *Inches.* | *Inch.* |
| 0–0·50 | ± 0·002 | 0–0·0156 | ± 0·001 |
| 0·51– ·75 | ± ·0025 | 0·0157– ·0312 | ± ·002 |
| ·76–1·00 | ± ·003 | ·0313– ·0625 | ± ·003 |
| 1·01–1·25 | ± ·0035 | ·0626– ·1250 | ± ·005 |
| 1·26–1·50 | ± ·004 | ·1251– ·2500 | ± ·008 |
| 1·51–1·75 | ± ·0045 | ·2501– ·3125 | ± ·0125 |
| 1·76–2·00 | ± ·005 | ·3126– ·3750 | ± ·0150 |
| 2·01 | ± (·25%) | | |
| *Millimetres.* | *Millimetres.* | *Millimetres.* | *Millimetre.* |
| 0–12·70 | ± 0·05 | 0–0·397 | ± 0·03 |
| 12·70–19·05 | ± ·06 | 0·40– ·79 | ± ·05 |
| 19·06–25·40 | ± ·08 | 0·791–1·59 | ± ·08 |
| 25·41–31·80 | ± ·09 | 1·591–3·17 | ± ·13 |
| 31·81–38·10 | ± ·10 | 3·171–6·35 | ± ·20 |
| 38·11–44·45 | ± ·11 | 6·351–7·94 | ± ·32 |
| 44·46–50·80 | ± ·13 | 7·941–9·53 | ± ·38 |
| 50·81 | ± (·25%) | | |

$$P = \frac{7000\,T}{R}$$

Where P = the hydrostatic pressure in pounds per square inch.
T = the thickness of the tube wall in inches.
R = the internal radius of the tube.

## INTERNATIONAL AIRCRAFT STANDARD SPECIFICATIONS.

### *2N3—Specifications for Spelter.*

1. GENERAL.—The general specifications, 1G1, shall form, according to their applicability, a part of these specifications.

2. MATERIAL.—(*a*) Under these specifications, virgin spelter—that is, spelter made from ore or similar raw material by a process of reduction

* The pressure to be applied shall be calculated from the formula given at the end of this specification.

and distillation or by electrolysis and not produced from re-worked metal—is recognized in five grades, as follows—

| | |
|---|---|
| *A* | High Grade |
| *B* | Intermediate |
| *C* | Brass Special |
| *D* | Selected |
| *E* | Prime Western |

3. COMPOSITION.—(*b*)

*A*. High Grade.—The spelter shall not contain over—

| | *Per cent.* |
|---|---|
| Lead | ·07 |
| Iron | ·03 |
| Cadmium | ·07 |

It shall be free from aluminium. The sum of the lead, iron, and cadmium shall not exceed ·10 per cent.

*B*. Intermediate.—The spelter shall not contain over—

| | *Per cent.* |
|---|---|
| Lead | ·20 |
| Iron | ·03 |
| Cadmium | ·50 |

It shall be free from aluminium. The sum of the lead, iron, and cadmium shall not exceed ·50 per cent.

*C*. Brass Special.—The spelter shall not contain over—

| | *Per cent.* |
|---|---|
| Lead | ·60 |
| Iron | ·03 |
| Cadmium | ·50 |

It shall be free from aluminium. The sum of the lead, iron, and cadmium shall not exceed 1 per cent.

*D*. Selected.—The spelter shall not contain over—

| | *Per cent.* |
|---|---|
| Lead | ·80 |
| Iron | ·04 |
| Cadmium | ·75 |

It shall be free from aluminium. The sum of lead, iron, and cadmium shall not exceed 1·25 per cent.

*E*. Prime Western.—The spelter shall not contain over—

| | *Per cent.* |
|---|---|
| Lead | 1·60 |
| Iron | ·08 |

*Sampling*.—(*c*) One slab shall be taken for analysis from each lot of 5000 pounds (2268 kg.) or less, but not more than 10 slabs need be taken from a car-load. Saw each slab completely across from the middle of one long side to the middle of the other and use the sawdust as the sample; or drill three 9-mm. holes along one diagonal of each slab, boring completely through and taking care to make fine drilling; the holes should be drilled as nearly as possible at the middle and halfway between either end and the middle of such diagonals. Go over the drillings or sawings with a powerful magnet to take out any iron which may have come from the drill or saw, and mix the sample thoroughly. The drill or saw must be thoroughly cleaned before use, and no lubricant shall be used in either drilling or sawing.

### 3N15—*Specifications for Brass Wire for Brazing.*

1. General.—The general specifications, 1G1, shall form, according to their applicability, a part of these specifications.

2. Material.—(*a*) The composition of the material shall be as follows—

| | *Per cent.* |
|---|---|
| Copper .. .. .. .. | 78·82 |
| Zinc .. .. .. .. | Remainder |
| Total impurities not greater than | 1·25 |
| Lead maximum .. .. | ·3 |
| Iron .. .. .. .. | ·1 |

*Analysis.*—(*a*) An analysis shall be made of samples taken from one bar of each lot of 25.

3. Manufacture.—(*a*) The bars shall be made from lake or electrolytic copper, conforming to the I.A.S.B. specification 2N2, and from virgin spelter conforming to the I.A.S.B. specification 2N3.

(*b*) No scrap shall be used in the manufacture of these bars other than that produced in the manufacturer's own plants and which is of the same composition as the material specified.

4. Delivery, Shipping, and Packing.—The wire shall be from ·187 to ·25 inch (4·76 to 6·35 mm.) in diameter and shall be furnished in bundles or coils of net weight not exceeding 220 pounds (100 kg.).

## BRONZES AND GUN-METAL

These metals are alloys of copper and tin in various proportions. The name "*gun-metal*" is usually applied to those alloys containing from about 85 to 92 per cent. of copper and the rest tin.

*Bell-metal* contains from about 70 to 85 per cent. of copper, the remainder being tin.

The harder grades of gun-metal contain from 85 to 87 per cent of copper, whilst the softer grades contain from 90 to 92 per cent. The type of gun-metal which is much used for bearings contains from 88 to 95 per cent. of copper.

If too much copper is present, the cast metal is porous and brittle, and if more than 25 per cent. of tin is present the metal rapidly becomes weaker and brittle.

The dividing line between the strong and brittle alloys is that at which the colour changes from golden-yellow (corresponding to from 75 or 80 to 97 per cent. of copper) to silver-white (corresponding to a copper content of less than 75 to 80 per cent.).

Table 39 shows the strength properties of the copper-tin series, for copper contents down to about 65 per cent. below which the alloys have no commercial value.

TABLE XXXIX.

PROPERTIES OF COPPER-TIN ALLOYS.

(U.S. Government Tests.)

| *Composition.* | | *Yield Point, tons per sq. inch.* | *Tensile Strength, tons per sq. inch.* | *Elongation per cent.* | *Compressive strength tons per sq. inch.* | *Compression, per cent.* |
|---|---|---|---|---|---|---|
| *Copper, per cent.* | *Tin, per cent.* | | | | | |
| 100 | 0 | 6·25 | 12·05 | 7 | 18·30 | 44 |
| 95 | 5 | 7·59 | 13·74 | 10 | 20·55 | 41 |
| 90 | 10 | 9·37 | 12·94 | 4 | 24·10 | 31 |
| 85 | 15 | 11·60 | 14·72 | 1·6 | 33·05 | 24 |
| 80 | 20 | 12·50 | 14·30 | 0·5 | 55·40 | 14 |
| 75 | 25 | 8·04 | 8·04 | — | 67·00 | 8 |
| 70 | 30 | 2·91 | 2·91 | — | 63·90 | 2 |
| 65 | 35 | 1·25 | 1·25 | — | 32·50 | 4 |

Fig. 32* shows the general properties of the copper-tin alloy series.

Another class of gun-metal is that containing copper, zinc, and tin, the general properties of which series are given in Table XXXIV; the gun-metals belonging to this series do not, as a rule, however, contain more than about 10 per cent. of zinc.

The following is the Admiralty specification for gun-metal—

| | *Per cent.* |
|---|---|
| Copper .. .. .. .. .. | 88 |
| Tin .. .. .. .. .. | 10 |
| Zinc .. .. .. .. .. | 2 |

The strength of this material should be as follows—

| | |
|---|---|
| Tensile strength .. | 14 tons per square inch |
| Elongation .. .. | 7½ " " " |

* Fourth Report of the Alloys Research Committee, *Proc. Inst. Mech. Engrs.*, 1897.

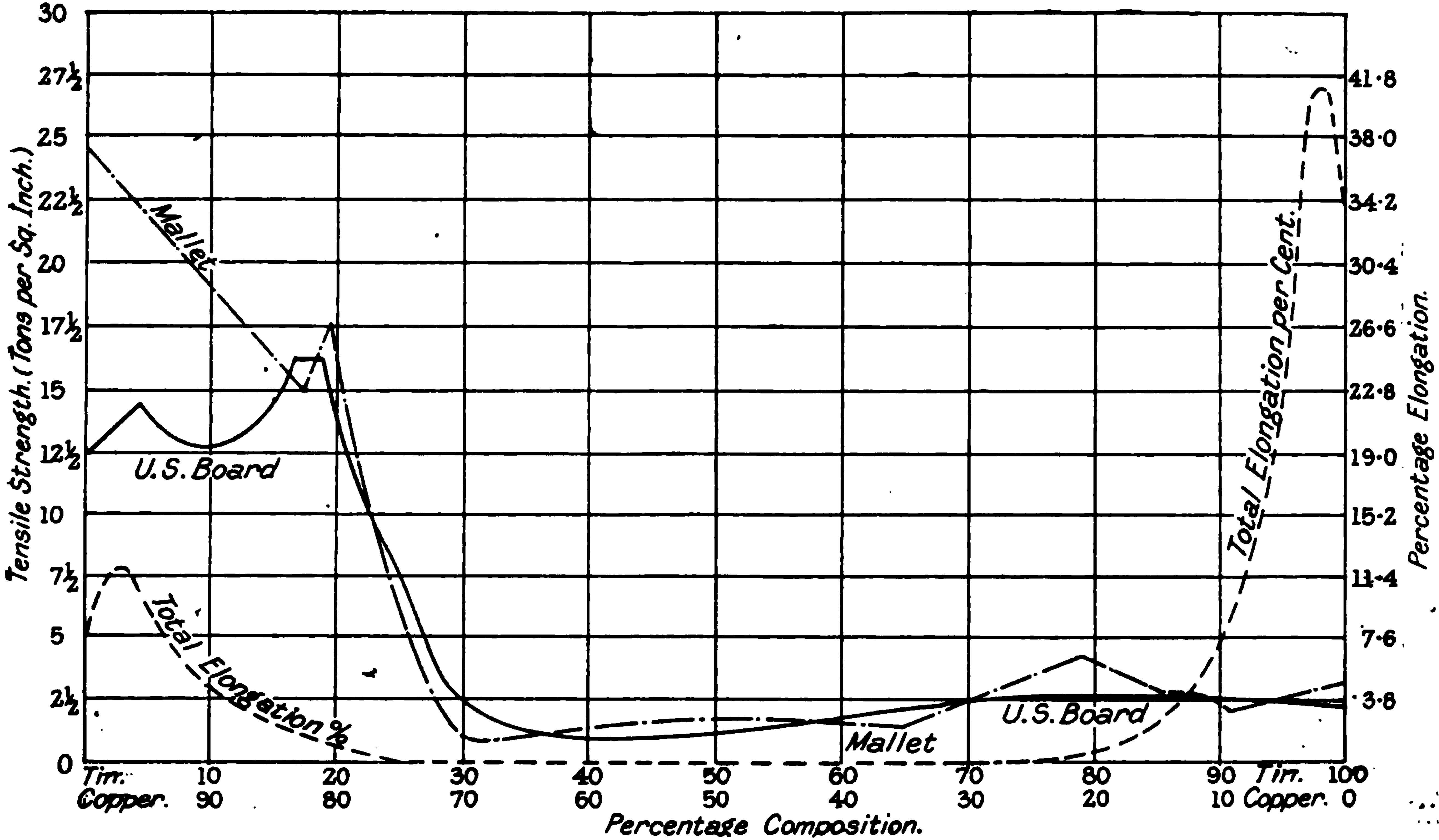



FIG. 32.—SHOWING THE MECHANICAL PROPERTIES OF COPPER-TIN ALLOYS.

## TABLE XL.

### Properties of Gun-Metals.

| *Metal.* | *Composition.* | | *Elastic Limit.* | *Tensile strength.* | *Elongation per cent. on 2 inches.* | *Specific Gravity.* |
|---|---|---|---|---|---|---|
| | *Copper.* | *Tin.* | | | | |
| Gun-metal (cast) .. | 90 | 10 | 7 | 15 | 15 | 8·5 |
| Gun-metal for guns (sand cast) .. .. .. | 90–92 | 10–8 | 5·6 | 11 | — | — |
| Gun-metal for guns (chill cast) .. .. .. | 90–92 | 10–8 | 6·7 | 17·6 | — | — |
| Gun-metal for guns, U.S. | 90 | 10 | – | 32–0 | — | 8·32 |
| tests. Metal cast under | 92 | 8 | — | 33·0 | — | — |
| pressure | 94 | 6 | — | 34·7 | — | 8·87 |
| Gun-metal* .. .. | 96·3 | 3·7 | — | 14·3 | 14·3 on 5 ins. | 8·65 |
| " .. .. | 92·5 | 7·5 | — | 12·5 | 7·4 " " | 8·68 |
| " .. .. | 87·5 | 12·5 | — | 13·9 | 3·6 " " | 8·65 |
| Bell-metal* .. .. | 82·5 | 17·5 | — | 16·2 | 0·7 " " | 8·79 |
| " .. .. | 80 | 20 | — | 14·7 | 0·4 " " | 8·74 |
| Gun-metal (rolled bar).. | 90 | 10 | — | 20–40 | 25–15 on 3ins. | 8·4–8·6 |

The modulus of elasticity found for the last five metals in the above table varied from 5570 to 6760 tons per square inch, and the bending modulus from 14 to 30 tons per square inch.

### Gun-metal for Bearings.

The type of gun-metal employed for bearings contains about 82 to 90 per cent. of copper, with a small amount of zinc (from 1 to 4 per cent.), and the balance tin.

The Admiralty gun-metal given on p. 100 is a good bearing metal.

Unwin† recommends the following composition for bearings: Copper, 82 per cent.; tin, 16 per cent.; zinc, 2 per cent.

The texture of a good bearing bronze or gun-metal is not uniform, but consists of whitish crystals or spots of alloy rich in tin distributed in a matrix of other metal; by rapidly cooling the cast metal, as in the chill casting process, the texture becomes finer and more uniform, the density greater, and the strength and toughness increased.

The composition of an average bronze which has been much used in automobile work for bearings experiencing

* Prof. R. H. Thurston.
† "Machine Design," Unwin, p. 16.

moderate wear is as follows: Copper, 76 per cent.; tin, 3 per cent.; lead, 1 per cent.; and zinc, 20 per cent.

Most of the 80 to 90 per cent. copper-tin alloys are suitable for bearing purposes, those with the higher copper contents being the harder.*

*Lead-bronzes* are also much used for bearing metals; a typical composition consists of: Copper, 64 per cent.; lead, 30 per cent.; tin, 5 per cent.; and nickel, 1 per cent. The nickel prevents the liquation of the lead. The resulting metal consists of a matrix of bronze with lead crystals or globules.

In further reference to the use of the so-called "Babbitt" metals for die-castings, particularly for aero-engine bearings, a soft metal of this class is more likely to squeeze or pound out under pressure due to its low compressive strength, whereas a hard babbitt is likely to crack and crumble under the hammering action of the piston. To overcome this, a babbitt-lined bronze backed bearing is now employed, and is widely used for aero and automobile engine work.

The following† bronze back alloys have been employed for this purpose—

TABLE XLI.

BRONZE ALLOYS FOR BEARING SHELLS.

| No. | *Percentage Composition.* | | | | | *Remarks.* |
|---|---|---|---|---|---|---|
| | *Copper.* | *Zinc.* | *Tin.* | *Lead.* | *Phosphorus* | |
| 1 | 85 | 5 | 5 | 5 | — | S.A.E. bronze specification |
| 2 | 84 | 2 | 5 | 9 | — | Very efficient material |
| 3 | 89 | — | 10 | — | 1 | |
| 4 | 80 | — | 10 | 10 | — | |
| 5 | 82 | — | 3 | 15 | — | |

* See also p. 145.

† C. Peck; The Doehler Die-Casting Co. See *Aviation*, 1st April, 1918.

**Effect of Impurities in Gun-Metal.**

*Nickel* has been found to have a beneficial effect upon ordinary gun-metal, in increasing its tensile strength.

*Lead* is usually present in gun-metal, and does not appear to seriously affect the strength; this metal does not alloy with bronze but separates out of the melted metal as it cools, in the form of globules, so that the resulting metal contains free lead. For certain bearing metals, known as lead-bronzes,* lead in large amounts may be advantageously employed.

*Zinc* has a beneficial effect in combining with the oxides and oxygen of the bronzes, producing greater fluidity and more uniform metal, free from blow-holes.

*Iron* has a markedly beneficial effect upon the mechanical properties,† but its effect upon the pouring qualities is bad; although the presence of a trace of aluminium will effect a marked improvement in this respect.

The effect of *manganese*, in Admiralty gun-metal, is to lower the mechanical strength properties and to render the castings unsound.

The effects of aluminium, phosphorus, manganese, and other elements when properly apportioned with bronze, will be considered subsequently.

### R.A.E. Specification for Gun-Metal Bar.

1. Application.—For parts which require to be non-rusting, such as unions, nipples, flanges.

2. Bars.—Bars as supplied by manufacturer not to be heated in any way before, during, or after machining.

3. The bars are to be sound, straight, free from twists, surface defects, and damaged ends, and must have a workmanlike finish. They are to be uniform in quality and capable of being machined easily and of taking a good finish.

4. The sizes of the bars are to be within the margin of manufacture as laid down by the E.S.C. in their Report, No. 32 (May. 1907), pp. 9 and 10.

5. Bars are to be supplied in bundles, and each bundle is to consist only of bars made from one cast, and every bundle is to be distinguished by its own registered number. This number is to be clearly stated in all correspondence and bills relating thereto.

* See the preceding paragraph.

† See "Delta Metals," p. 121 *et seq.*

6. Tests.—Test specimens taken from any bar are to comply with the following mechanical tests—

(a) *Tensile Test.*—The tensile test is to be made on the British Standard Test piece (·564 inches diameter × 2 inches acting length), or on a specimen which has the same geometrical proportions—

| | *Bars under ½ inch diameter.* | *Bars ½ inch diameter and over.* |
|---|---|---|
| Ultimate Stress .. .. | 30 tons per sq. inch | 28 tons per sq. inch |
| Yield Point .. .. | 15 ,, ,, | 14 ,, ,, |
| Reduction of area, Elongation on 2 inches | 26 per cent.* | 26 per cent.* |

7. The above test values are minima. If any one of the test pieces fails to pass the specified test, the bar or bars represented by the defective specimen will be rejected.

8. No test piece will be annealed, hammered, or otherwise treated after its removal from the bar.

9. The manufacturer must replace, free of charge, all material consumed in testing and found to be defective.

## R.A.E. Specification for Gun-Metal Castings.

Gun-Metal Alloy.—The alloy from which the castings are made is to consist of the following metals—

| | *Per cent.* |
|---|---|
| Copper .. .. .. .. | 87–88 |
| Tin .. .. .. .. | 10–10·5 |
| Zinc .. .. .. .. | 2– 2·5 |

1. Castings.—The castings are to be sound, free from blow-holes, and possess a good uniform colour.

2. The castings must be delivered with surfaces clear and free from sandy or hard skin, in order that they may be capable of being machined easily and of taking a good finish.

1. Machining Allowances.—Such allowances are to be left on the castings where machining is indicated, in order that the machinist can produce the finished parts to the required dimensions.

2. The casting dimensions not necessitating machining must be quite accurate to the drawing.

3. If requested, the contractor must submit a sample casting to R.A.E. for approval before proceeding with the order.

Tests.—Test pieces taken, as requested hereunder, are to comply with the following mechanical tests—

*Tensile Test.*—

| | |
|---|---|
| Ultimate Stress .. .. .. | .. 14 tons per square inch |
| Yield Point .. .. .. | .. 7·5 ,, ,, |
| Elongation on 2 inches .. .. | .. 10 per cent. |
| Reduction of area .. .. | .. 20 ,, |

1. The tensile test is to be made on the British Standard Test piece (·564 inch diameter × 2 inches actual length), or on specimens which have the same geometrical proportions.

* The percentage figures for elongation and reduction of area, when added together, must exceed 26.

2. The above test values are minima. If any one of the test pieces fails to pass the specified tests the casting or castings represented by the defective specimen will be rejected.

3. The test specimens are to be prepared from sample pieces cast near the top of the castings, and the number of such pieces for each order will be separately stated.

4. No test piece will be annealed, hammered, or otherwise treated after its removal from the casting.

5. The contractor must replace, free of charge, all castings found to be defective or which have failed to pass the required test.

## ALUMINIUM BRONZE

The effect of aluminium, up to about 12 per cent., upon the properties of copper is shown graphically in Fig. 33.* It

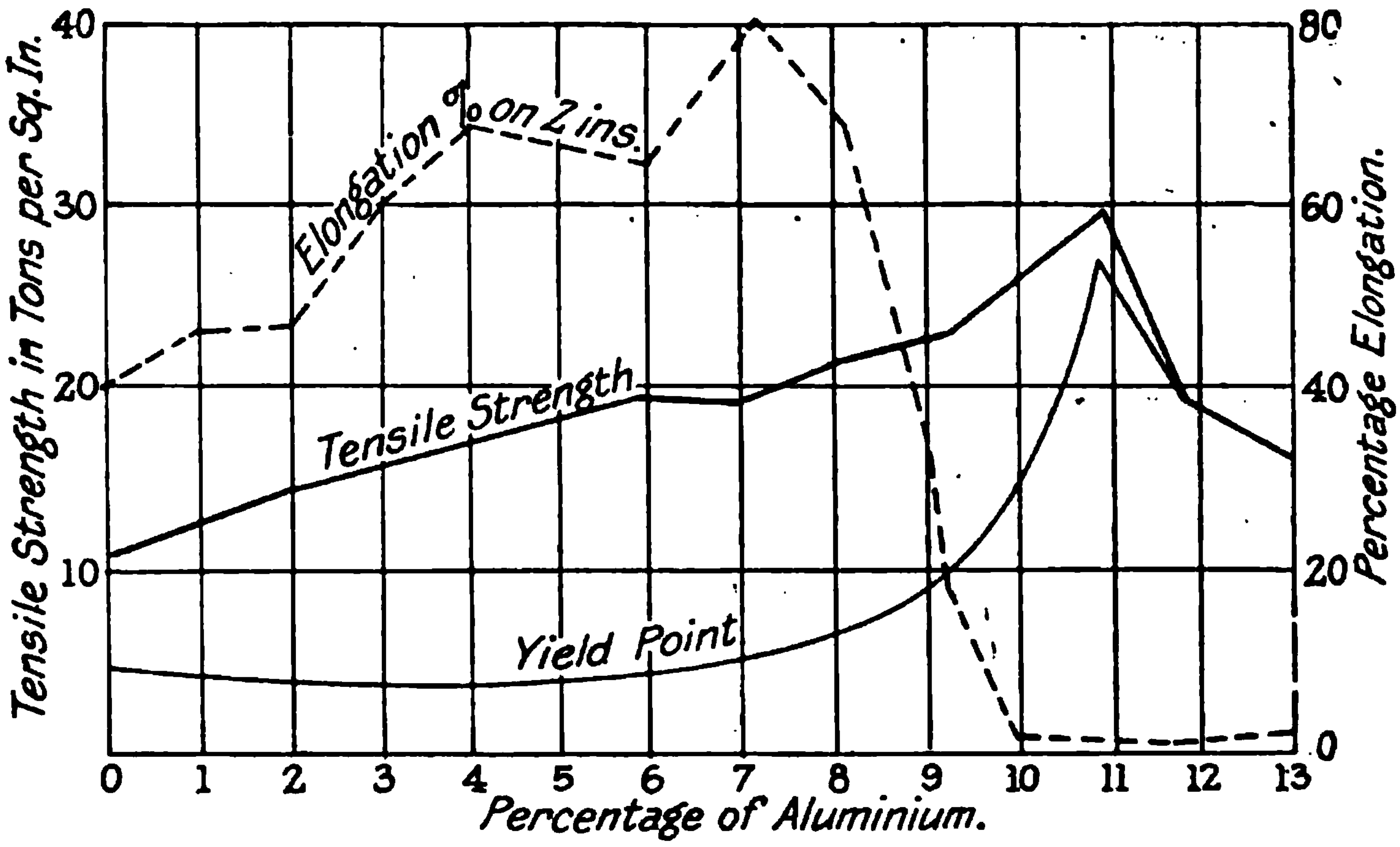



FIG. 33.—EFFECT OF ALUMINIUM ON THE STRENGTH OF BRONZE.

will be seen that up to about 10 per cent. both the yield point and tensile strength progressively increase; beyond about this amount there is a rapid decrease in both the strength and the ductility, and the resulting alloys are of no industrial importance. Alloys containing up to 7·35 per cent. of aluminium have a low yield point, moderate tensile strength, but great ductility, whereas those containing from 7·35 to 10 per cent. have a low yield point and high tensile strength, but low ductility.

* Eighth Report of Alloys Research Committee, *Proc. Inst. Mech. Engrs.*, 1907.

The aluminium bronzes used commercially contain from about 2 to 10 per cent. of aluminium, and they are noted for their high tensile strength and toughness.

Aluminium bronze is malleable, both hot and when cold; it is also noted for its resistance to corrosion.

This type of bronze is supplied commercially in five grades, as follows—

| | | | | | |
|---|---|---|---|---|---|
| Grade .. .. | *A* | *B* | *C* | *D* | *E* |
| Per cent. aluminium | 10 | 7½ | 5 | 2½ | 1¼ |

The properties of these grades is shown by the values given in Table 42.

TABLE XLII.

PROPERTIES OF ALUMINIUM BRONZES.

| *Grade.* | *Percentage of Aluminium.* | *Yield Point.* | *Tensile Strength.* | *Elongation per cent.* | *Specific Gravity.* |
|---|---|---|---|---|---|
| | | *Tons per square inch.* | | | |
| — | 11 | 14–25 | 40–45 | 8 | 7·23 |
| *A* | 10 | 13–18 | 33–40 | 14 | 7·69 |
| *B* | 7½ | 8–11 | 25–30 | 40 | 8·00 |
| *C* | 5 | 4–7 | 15–18 | 40 | 8·37 |
| *D* | 2½ | 3–5 | 13–15 | 50 | 8·69 |
| *E* | 1¼ | 3–4 | 11–13 | 55 | — |

**Casting Aluminium Bronze.**

Aluminium bronze shrinks more than ordinary brass, and when poured it solidifies rapidly, so that it is necessary to pour it quickly, the feeders being of ample size. Baked sand moulds are preferable to those of green-sand, except for small castings.

It is important to cast this type of bronze at the correct temperature, as the mechanical properties are appreciably affected by small changes in the casting temperature. The following table,* which refers to the properties of an aluminium-copper alloy containing 4·63 per cent. of aluminium, will serve to illustrate this point.

* *Proc. Inst. Mech. Engrs.*, 1907, p. 62.

TABLE XLIII.

EFFECT OF CASTING TEMPERATURE UPON STRENGTH OF ALUMINIUM BRONZE.

| *Casting Temperature.* | *Yield Point, tons per sq. inch.* | *Tensile Strength, tons per sq. inch.* | *Elongation in 2 inches per cent.* |
|---|---|---|---|
| 650°C. | 5·6 | 9·68 | 8·5 |
| 724°C. | 5·0 | 7·04 | 5·5 |
| 707°C. | 4·5 | 4·89 | 3·0 |

In the case of bronzes containing up to 9 per cent of aluminium, chill casting gives better strength properties than ordinary sand casting.

**Effect of Annealing Aluminium Bronze.**

In the case of 9·9 per cent. aluminium bronze, the alloy is very sensitive to heat treatment, and its strength properties are markedly affected by the annealing temperature, more particularly when annealing occurs between 300° C. and 400° C., as the following results show—

TABLE XLIV.

EFFECT OF ANNEALING UPON STRENGTH PROPERTIES OF 9·9 PER CENT. ALUMINIUM BRONZE.

| *Heat Treatment.* | *Yield Point, tons per sq. inch.* | *Tensile Strength tons per sq. inch.* | *Elastic ratio.* | *Elongation in 2 inches per cent.* | *Reduction of area, per cent.* |
|---|---|---|---|---|---|
| Bar as rolled .. .. | 14·8 | 38·1 | 0·39 | 28·8 | 30·80 |
| Annealed for 1 hr. at 300° | 14·6 | 38·04 | 0·38 | 27·0 | 33·06 |
| ,, ,, ,, 400° | 23·4 | 31·69 | 0·74 | 2·5 | 2·86 |
| ,, ,, ,, 500° | 20·5 | 34·08 | 0·60 | 9·5 | 13·11 |
| ,, ,, ,, 600° | 15·7 | 31·74 | 0·50 | 9·0 | 14·50 |
| ,, ,, ,, 700° | 15·1 | 31·85 | 0·48 | 9·0 | 11·25 |
| ,, ,, ,, 800° | 12·7 | 26·23 | 0·48 | 13·5 | 21·60 |
| ,, ,, ,, 900° | 13·3 | 21·95 | 0·61 | 6·0 | 8·70 |

It will be noted that there is a marked reduction in the ductility, but an increase in the elastic ratio (nearly 100 per cent.) when the alloy is annealed at 400° C. instead of 300° C.

## Effect of Quenching Aluminium Bronze.

In the case of the 9·9 per cent. aluminium bronze previously considered, the effect of quenching it in water from different temperatures is to raise the yield point and tensile strength, but to reduce the ductility.

The higher the quenching temperature, up to 900° C., the higher will be the mechanical strength; at this temperature an ultimate stress of over 50 tons per square inch, with 3 per cent. elongation, is obtained. The following table shows the effect of quenching at various temperatures—

TABLE XLV.

EFFECT OF QUENCHING UPON STRENGTH PROPERTIES OF 9·9 PER CENT. ALUMINIUM-BRONZE.

| *Quenching Temperature.* | *Yield Point, tons per sq. inch.* | *Tensile Strength, tons per sq. inch.* | *Elastic Ratio.* | *Elongation in 2 inches per cent.* | *Reduction of area, per cent.* |
|---|---|---|---|---|---|
| 600°C. | 17·0 | 38·18 | 0·45 | 22·2 | 30·00 |
| 700°C. | 18·1 | 39·76 | 0·46 | 15·4 | 20·60 |
| 800°C. | 32·4 | 43·57 | 0·75 | 7·0 | 14·29 |
| 900°C. | 39·8 | 51·51 | 0·77 | 3·0 | 4·83 |

## Working Aluminium Bronze.

All grades, except Grade A, of this metal can be rolled, drawn, swaged, forged hot, and spun. The metal should be worked hot at a red heat.

The mechanical properties of aluminium bronze are improved by rolling and drawing, with or without annealing.

When rolling, swaging, drawing, or spinning the metal in the cold state it should be annealed often, and at a brighter red-heat than that employed for brass.

The metal can be soldered with ease; it is advisable to

use a solder of pure block tin, and to employ "killed spirits" or zinc-chloride as a flux.

The metal will also braze readily, with a brazing metal consisting of equal parts of copper and zinc, using borax or cryolite as a flux.

**Copper-Aluminium-Manganese Alloys.**

A series of alloys of copper with from 0 to 7 per cent. of aluminium and from 0 to 7 per cent. of manganese has been tested,* and the results show some interesting properties of these alloys.

It was found difficult to cast the metal in the ordinary way, even with pre-heated cast iron moulds, dressed with black-lead, owing to the inclusion of dross, and small particles of the charcoal used to cover the molten metal in the crucible. The use of cryolite as a flux improved the casting properties, but the only satisfactory method was the pressure-casting one. In this process the liquid metal in the crucible was forced through a feeder tube or pipe extending nearly to the bottom of the crucible, to the mould, by means of air-pressure. The mould was placed vertically above the crucible, which itself was placed in an air-tight chamber provided with asbestos joints, and the temperature of the metal in the mould varied from 500 to 600° C. The air pressure required to obtain satisfactory castings was about 30 pounds per square inch, and this pressure was maintained until the ingot or casting was solid.

Slabs measuring 14 inches × 7 inches × 1½ inches were cast in this manner and were hot rolled at about 800° C., from 1½ inches down to ⅜ inch, and cold rolled, after pickling, down to a thickness of 0·14 inch. The thinnest material rolled was 0·04 inch thick.

The alloys were annealed, for cold rolling purposes, between 650° C. and 750° C.

* "The Properties of Some Copper Alloys," Dr Rosenhain and D. Hanson. *Journ. Inst of Metals*, April, 1919.

The following are the compositions of the alloys tested—

TABLE XLVI.

COMPOSITIONS OF COPPER-ALUMINIUM-MANGANESE ALLOYS.

| *No. of Alloy* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aluminium | 3 | 5 | 7 | 3 | 5 | 7 | 3 | 6 | 2 | 4 | 0 | 0 |
| Manganese | 0 | 0 | 0 | 1 | 1 | 1 | 3 | 3 | 5 | 5 | 5 | 7 |
| Copper .. | 97 | 95 | 93 | 96 | 94 | 92 | 94 | 91 | 93 | 91 | 95 | 93 |

It will be observed that the range of compositions includes both the binary copper-aluminium and copper-manganese alloys.

TABLE XLVII.

PROPERTIES OF COPPER-ALUMINIUM-MANGANESE ALLOYS.

| *No. of Alloy.* | *Condition.* | *Yield Point, tons per sq. inch.* | *Tensile Strength, tons per sq. inch.* | *Elongation in 2⅜ inches per cent.* | *Brinell No.*† |
|---|---|---|---|---|---|
| 1 | As Rolled .. | 26·6 | 26·8 | 9 | 137·5 |
| | Annealed* .. | 5·8 | 17·7 | 55 | 60 |
| 2 | As Rolled .. | 34·3 | 35·1 | 16·5 | 174·5 |
| | Annealed* .. | 8·3 | 25·5 | 70 | 84·5 |
| 3 | As Rolled .. | 38·7 | 39·8 | 17·5 | 195 |
| | Annealed* .. | 7·0 | 27·5 | 71 | 75·5 |
| 4 | As Rolled .. | 26·2 | 26·8 | 11·5 | 141·5 |
| | Annealed* .. | 10·0 | 20·2 | 50 | 72·5 |
| 5 | As Rolled .. | 28·7 | 31·1 | 27 | 162·5 |
| | Annealed* .. | 12·0 | 26·3 | 57 | 89·5 |
| 6 | As Rolled .. | 34·1 | 35·5 | 28 | 184 |
| | Annealed* .. | 11·5 | 29·3 | 65 | 99·5 |
| 7 | As Rolled .. | 27·3 | 27·7 | 12 | 140 |
| | Annealed* .. | 10·2 | 21·4 | 48 | 78·5 |
| 8 | As Rolled .. | 38·2 | 39·0 | 12 | — |
| | Annealed* .. | 13·7 | 29·8 | 58 | — |
| 9 | As Rolled .. | 29·6 | 29·9 | 9 | 145·0 |
| | Annealed* .. | 10·4 | 22·4 | 45 | 83·0 |
| 10 | As Rolled .. | 35·0 | 35·7 | 15·5 | 182 |
| | Annealed* .. | 11·3 | 26·7 | 55 | 95 |
| 11 | As Rolled .. | 29·3 | 29·3 | 9 | 149·5 |
| | Annealed* .. | 9·2 | 21·0 | 45 | 81 |
| 12 | As Rolled .. | 29·4 | 29·4 | 8·5 | 182 |
| | Annealed* .. | 10·6 | 22·1 | 44 | 95 |

* Annealed at 650° for half an hour and cooled in air.

† Brinell tests made upon strips 0·14 inch thick, using 5 mm. ball and a load of 300 kilogrammes.

## PHOSPHOR-BRONZE

Phosphorus, when added to bronze in small quantities, acts as a de-oxidizer and renders the metal more fluid; not more than 0·15 per cent. is necessary for this purpose.

When from 0·2 to 10 per cent. is present, both the strength and ductility are appreciably increased.

The phosphorus is usually added to the metal in the form of phosphor-tin or phosphor-copper.

Phosphor-bronzes containing less than 9 per cent. of tin and up to 0·25 per cent. of phosphorus are forgeable and non-corrodible, and are used for drawing into rod and wire.

Phosphor-bronzes for casting purposes usually contain from 8 to 14 per cent. of tin and from 0·25 to 1·0 per cent. of phosphorus.

The following are typical compositions of phosphor-bronzes :

TABLE XLVIII.

COMPOSITIONS OF PHOSPHOR-BRONZES.

| *Material.* | *Compositions per cent..* | | | |
|---|---|---|---|---|
| | *Copper.* | *Tin.* | *Phosphorus* | *Lead.* |
| Phosphor-bronze for bearings (Unwin) | 79 | 10 | 1 | 10 |
| Admiralty specification .. .. | 83 | 10 | Copper phosphide, 7 | |
| Phosphor-bronze for automobile engine bearings (*Engineering*, 17th Jan., 1913) .. .. .. | 88·2 | 11·0 | 0·2 | 0·6 |
| Phosphor-bronze for railways .. | 79·7 | 10·0 | 0·8 | 9·5 |
| International Aircraft Standard* Specification for phosphor-bronze castings for bearings .. .. | 79·00–81·00 | 9·00–11·00 | 0·10–0·30 | 9·00–11·00 |
| I.A.S.B. Specification for phosphor-bronze strip for springs .. .. | 91–93 | 6·5–9 | 0·15 max. | *Zinc*, 0·2 max *Iron*, 0·1 max |

The tensile strength of phosphor-bronze in the cast state varies from 14 to 18 tons per square inch, with a yield point of from 5 to 7, and an elongation of from 1·0 to 0·5.

When the metal is chill-cast, both its strength and ductility increase; the yield point then varies from 8 to 12, and the tensile strength from 18 to 24 tons per square inch, with corresponding elongations of from 2 to 5 per cent.

* The total impurities should not exceed 0·25 per cent.

In the case of the softer grades of phosphor-bronze, the tensile strength varies from 18 to 22 tons per square inch, with an elongation of from 25 to 30 per cent.

Rolling and drawing increase the strength of the metal.

Phosphor-bronze wire can be drawn, having a tensile strength (for 16 B.W.G.) of from 120 to 150 tons per square inch; when annealed, the tensile strength varies from 40 to 75 tons per square inch. This wire is used for electrical and non-corrosive metal purposes.

When phosphor-bronze is cast in water-cooled iron moulds, it is found that the structure of the metal is rendered much closer and finer, and that the strength and ductility are appreciably increased; this method of rapidly cooling the metal in the mould is the basis of the Eatonia process.*

The rapid cooling appears to prevent the segregation of the different constituents of the alloy, which normally progressively separate out at the different critical points during cooling.

Figs. 34 and 35 are micrographs of phosphor-bronze from the same mixture, the former photograph representing the untreated sand cast metal, which had a tensile strength of 13 tons per square inch, whilst the other treated metal had a tensile strength of 21 tons per square inch.

The results of this treatment are that the metal is much more homogeneous, and therefore wears better for bearing purposes, and that the tensile strength is increased by from 40 to 50 per cent. The ductility is also considerably improved, and the results of tests show that elongations of from 30 to 55 per cent. are obtainable in the case of bronzes having yield points of from 7 to 11, and tensile strengths of from 19 to 23 tons per square inch.

This process is equally applicable to the cases of other alloys, such as brasses, white metals, and other bearing metals. Gun-metal and phosphor-bronze bearings for aircraft

* Employed by Yorkshire Engineering Supplies, Ltd., Messrs. Willans & Robinson, and others.

Fig. 34.—Sand Cast Phosphor-Bronze.

Fig. 35.—Eatonia Cast Phosphor-Bronze.

engines and for automobile purposes are frequently cast in the above manner, with highly satisfactory results.

The type of phosphor-bronze employed for aeroplane and car engines should have a tensile strength of about 20 tons per square inch.

Figs. 36 and 37 show the micro-structure of automobile phosphor-bronze to different magnifications.

## International Aircraft Standard Specifications for Phosphor-Bronze.

### 3N9.—*Specification for Phosphor-Bronze Strip.*

1. General.—The general specifications, 1G1, shall form, according to their applicability, a part of these specifications.

2. Use.—This strip to be used for springs.

3. Material.—(*a*) The bronze shall conform to the following chemical composition—

| | *Per cent.* |
|---|---|
| Copper .. .. .. .. | 91–93 |
| Zinc, maximum .. .. | 0·20 |
| Iron, maximum .. .. | 0·10 |
| Phosphorus, maximum .. | 0·15 |
| Tin .. .. .. .. | Remainder |

(*d*) Drillings or clippings for analysis shall be taken from both ends of the coil sampled and shall be free from all surface oxide or dirt.

4. Manufacture.—(*a*) The bronze shall be crucible melted from lake or electrolytic copper, according to I.A.S.B. specification 2N2 and best Straits or equivalent tin and deoxidized with phosphorus.

(*b*) No scrap shall be used except such as may accumulate in the manufacturer's plants from material of the same composition and of their own make.

(*c*) All strip shall be rolled to spring temper unless otherwise ordered.

5. Workmanship and Finish.—The surface of the strip shall be clean and smooth, and it shall be free from injurious defects such as blisters, slivers, or dirt embedded in the surface.

6. Physical Properties and Tests.—Phosphor-bronze spring strip shall have the following physical properties—

| *Tensile Strength.* | *Yield Point.* | *Elongation in 2 inches* (50·8 *mm.*) |
|---|---|---|
| Minimum, 85,000 pounds per sq. inch (59·76 kg./mm.) | 65,000 pounds per sq. inch (45·70 kg./mm.$^2$) | 5 per cent. |
| Maximum, 115,000 pounds per sq. inch (80·85 kg./mm$^2$.) | 95,000 pounds per sq. inch (66·79 kg./mm.$^2$) | 20 per cent. |

FIG. 36.—AUTOMOBILE BEARING, PHOSPHOR-BRONZE. MICROGRAPH MAGNIFIED 24 TIMES.

FIG. 37.—THE SAME METAL AS SHOWN IN FIG. 36, BUT MAGNIFIED 240 TIMES.

7. Selection of Test Specimens.—When shipments are made in coils, a specimen from every tenth coil shall be taken for physical tests. When shipments are made in short lengths, a specimen will be taken from each case.

8. Dimensions and Tolerances.—The tolerances allowed shall be given in the following table—

*Tolerances.*—

English Units.

| *American Wire gauge (B. & S.).* | *Thickness, inches.* | *Less than 5 inches wide.* | *Tolerance, Inches.* | | |
|---|---|---|---|---|---|
| | | | *5–8 inches wide.* | *8–11 inches wide.* | *11–14 inches wide.* |
| No. 8–14 | 0·1285–0·0641 | ± 0·0029 | ± 0·0033 | ± 0·0036 | ± 0·0040 |
| „ 15–18 | 0·0571–0·0403 | ± 0·0025 | ± 0·0029 | ± 0·0033 | ± 0·0037 |
| „ 19–24 | 0·0359–0·0201 | ± 0·0020 | ± 0·0024 | ± 0·0028 | ± 0·0032 |
| „ 25–28 | 0·0179–0·0126 | ± 0·0016 | ± 0·0020 | ± 0·0024 | ± 0·0028 |
| „ 29–32 | 0·0113–0·0080 | ± 0·0013 | ± 0·0017 | ± 0·0020 | ± 0·0024 |

## *3N3—Specifications for Phosphor-Bronze Castings for Bearings.*

1. General.—The general specifications, 1G1, shall form, according to their applicability, a part of these specifications.

2. Use.—This material is suitable for liners in babbitted bearings

3. Material.—The chemical composition shall be as follows—

| | *Per cent.* |
|---|---|
| Copper .. .. .. .. | 79·00–81·00 |
| Tin .. .. .. .. | 9·00–11·00 |
| Lead .. .. .. .. | 9·00–11·00 |
| Phosphorus .. .. .. | 0·10– 0·30 |
| Total impurities, maximum | 0·25 |

4. Manufacture.—(*a*) The material shall be made from lake or electrolytic copper conforming to the I.A.S.B. specification, 2N2, and from pig tin at least 99 per cent. pure.

(*b*) No scrap shall be used other than that produced in the manufacturer's own plants and which is of the same composition as the material specified.

5. Workmanship and Finish.—Castings shall be homogeneous and free from shrinkage cracks, spongy spots, blow-holes, and foreign matter. Castings in which defects are revealed by machining operations shall be replaced by the manufacturer. The full weight of the original material in rejected castings shall be returned to the manufacturer.

6. Dimensions and Tolerances.—Castings must be true to pattern; cores must be correctly placed. Surfaces which are to be machined shall admit of finishing to the required dimensions without leaving any trace of the original surface.

TABLE LXIX.

EFFECT OF TEMPERATURE UPON THE STRENGTH OF PHOSPHOR BRONZE. (Unwin.)

| *Temperature, °F.* | *Tensile Strength in tons per sq. inch.* | *Elongation, per cent on 2 inches.* | *Reduction of area, per cent.* |
|---|---|---|---|
| Atmospheric | 16·06 | 13·5 | 10·0 |
| 270 | 14·16 | 12·5 | 12·4 |
| 350 | 12·26 | 7·5 | 10·0 |
| 430 | 12·41 | 10·5 | 8·7 |
| 500 | 11·10 | 6·0 | 6·3 |
| 600 | 8·17 | 3·5 | 2·5 |

## MANGANESE BRONZE

Manganese bronze, or "brass," is obtained by adding a small amount of ferro-manganese to bronze or brass; the effect of the manganese is to deoxidize the resulting metal. The colour of commercial manganese bronze is whitish, and for this reason it is sometimes known as "white bronze." The proportion of manganese present varies from 0·10 to about 20 per cent., according to the purpose; the usual quantities of manganese present in the malleable bronzes varies from 1 to 5 per cent.

The following are typical analyses of manganese bronzes—

TABLE L.

ANALYSES OF MANGANESE BRONZES.

| *No.* | *Description.* | *Composition per cent.* | | | | | |
|---|---|---|---|---|---|---|---|
| | | *Copper* | *Zinc* | *Manganese* | *Iron* | *Silicon* | *Lead.* |
| 1 | Silver bronze (rolled bar) | 67·5 | 13·0 | 18 | — | 0·5 | *Alu.* 1·20 |
| 2 | Parsons' sheet alloy | 60·27 | 37·52 | 0·01 | 1·41 | 0·75 | 0·01 |
| 3 | Casting bronze | 56·11 | 41·34 | 0·01 | 1·30 | 0·75 | 0·01 *Alu.* 0·47 |
| 4 | Sperry's sheet alloy | 60·00 | 38·00 | 0·10 | 1·25 | 0·65 | — |
| 5 | Sand casting bronze | 56·00 | 42·38 | 0·12 | 1·25 | 0·75 | *Alu.* 0·50 |
| 6 | 'Magnetic' bronze | 60 | — | 26·8 | — | — | *Alu.* 13·2 |
| 7 | Forgeable bronze | 96–97 | — | 4–3 | — | — | — |

The tensile strenth of No. 1 alloy in the above table is about 25 tons per square inch, with 20 per cent. elongation;

this metal can be rolled into thin plate and drawn into wire of $\frac{8}{1000}$ths of an inch diameter, the wire having a better electrical conductivity than German silver. The commercial grades of manganese bronze, with from 1 to 5 per cent. of manganese, have a tensile strength of from 20 to 30 tons per square inch, in the rolled condition with an elastic limit of 15 to 23 tons per square inch, the elongation varying from 12 to 20 per cent.

Cast manganese bronze has a tensile strength of 18 to 24 tons per square inch, with an elongation of from 8 to 12 per cent.

Manganese bronze is chiefly used for bolts, nuts, pump-rods, ship's plates, and propellers; it can be forged at a cherry-red heat and is rolled into plates or sheets, either hot or cold.

Manganese bronzes with from 2 to 4 per cent. of manganese present retain their mechanical strength properties to marked extent at high temperatures.

## SILICON BRONZE

These bronzes are alloys of copper and silicon, in which the silicon present ranges from 3 to 5 per cent.; the effect of the silicon is to increase both the strength and the hardness of the metal up to about 5 per cent., beyond which the metal becomes brittle.

The following are the properties of this bronze—

TABLE LI.

PROPERTIES OF SILICON BRONZES.

| *Composition, per cent.* | | *Tensile Strength in tons per sq. inch.* | *Percentage Elongation* | *Remarks.* |
|---|---|---|---|---|
| *Silicon.* | *Copper.* | | | |
| 3 | 97 | 24–26 | 50–60 | Cast condition |
| 5 | 95 | 30–36 | 8 | |
| 2–5 wire | 98–95 | 18–45 | — | Telegraph and telephone wire |

Silicon bronze is noted for its strong resistance to corrosion in the air of manufacturing towns, and as it has an electrical

conductivity equal to between 35 and 95 per cent. (according to its composition) of that of pure copper, it is much used for telegraph and telephone wires.

## TITAN BRONZE

This is an alloy of copper and zinc, having a golden colour. It possesses good non-corrosive properties and is fairly malleable ; it can be forged from a cherry-red to a black heat.

This metal, on account of its strength and resistance to corrosion, is used for under-water fittings, bolts, nuts, marine shafts, pump-rods, etc.

In the cast state its tensile strength is from 25 to 28 tons per square inch, with an elastic limit of from 15 to 18 tons per square inch, and with from 15 to 20 per cent. elongation in 2 inches.

In the forged or rolled state its tensile strength is from 30 to 36 tons per square inch, with an elastic limit of from 18 to 21 tons per square inch, and with an elongation of about 40 per cent. in 2in. ; the reduction in area varies from 45 to 50 per cent.

## TOBIN BRONZE

This is another of the marine bronzes used in America, and is noted chiefly for its non-corrosive and its high strength properties. Tobin bronze contains copper and zinc, with small quantities of tin, antimony, lead, and iron.

The following are typical analyses of this bronze—

TABLE LII.

COMPOSITIONS OF TOBIN BRONZES.

| *Copper.* | *Zinc.* | *Tin.* | *Antimony.* | *Iron.* | *Remarks.* |
|---|---|---|---|---|---|
| 59–61 | 37–38 | 1–2 | 0·30–0·35 | 0·1–0·2 | (Hughes) |
| 58·22 | 39·48 | 2·30 | — | — | Ordinary composition (Thurston) |
| 59·00 | 38·40 | 2·16 | *Lead,* 0·31 | 0·11 | Pig metal (Dr. Dudley) |
| 61·20 | 37·14 | 0·90 | *Lead,* 0·35 | 0·18 | Rolled bar (Dr. Dudley) |

The tensile strength of cast tobin bronze is from 24 to 28 tons per square inch, and its specific gravity is about 8·40.

The tensile strength, in the hot-rolled state, is from 30 to 36 tons per square inch, and when cold-rolled its tensile strength can be increased up to 44 tons per square inch.

This metal can be forged at a cherry-red heat and can be stamped as readily as steel.

It is very applicable for stamped, forged, and rolled parts for marine, seaplane, and flying-boat work, and it is also used for pump-rods, steam and sea-water valves, propeller shafts, bolts, nuts, and valve stems, etc.

## "DELTA" BRAND ALLOYS

The metals known under the name "Delta" comprise a great variety of alloys of widely different composition. A series of these alloys consists of copper-zinc combinations containing small proportions of other elements, such as tin, iron, etc.; these form a very valuable group of high-tensile alloys suitable for aircraft, automobile, electrical, and general engineering work.

The effect of the addition of iron and certain other elements is to increase the strength of the alloy to a marked degree, but special methods, notably those of the Delta Metal Co., Ltd., have to be employed for ensuring the correct chemical combination or admixture of the iron. The usual method adopted is to alloy the iron and zinc in proper proportions beforehand; when ordinary soft iron is added to molten zinc, the former readily alloys or goes into solution with the latter, up to the extent of about 5 per cent. or more. If the zinc-iron alloy is then added to the copper, it is possible to introduce a suitable percentage of iron into the resulting alloy.

The following are the ranges of compositions of these alloys—

| *Designation.* | *Copper.* | *Zinc.* | *Iron.* | *Tin.* |
|---|---|---|---|---|
| Sterco Metal . . | 60 | 44 | 2–4 | 1–2 |
| *A* . . . . . . | 50–65 | 49·9–30 | 0·1–5·0 | — |
| *B* . . . . . . | 98–40 | 1·8–45 | 0·1–5·0 | 0·1–10 |

Delta Bronze Metal is supplied commercially in four grades, known as Delta Bronze No. I, Delta Bronze Silver No. II, Delta Bronze No. III, and Delta Bronze No. IV respectively, each of which has its own range of applications.

Delta Bronze No. I is noted for its high strength and resistance to corrosion ; it is one of the malleable bronzes.

Delta Silver Bronze No. II is a " white or silver bronze " of high strength and of silver white colour, suitable for ornamental purposes.

Delta Bronze No. III is used chiefly for solid drawn hydraulic tubes.

Delta Bronze No. IV is the most widely used malleable bronze. It is proposed to consider the properties of each of these metals in turn.

Fig. 38 shows the general tensile strength and elongation properties of the various metals.

### Delta Bronze No. I.

This is one of the malleable non-ferrous metals having a high tensile strength, varying from about 40 tons per square inch, in the cast state, up to nearly 50 tons per square inch in the extruded condition, the corresponding average elongations being about 20 and 25 per cent. respectively.

This metal has a fine golden colour and it takes a high polish. It is hard, but not brittle, and possesses a great resistance to corrosion, so that it is capable of replacing low and medium carbon steels of equal strength in cases where the latter would be exposed to corrosive agents.

Delta Bronze No. I, when heated to a dull red heat, becomes soft and malleable, and it can be readily stamped and forged ; it is much stronger and more homogeneous in the wrought than in the cast state.

This metal is used for marine engines, mining, hydraulic, and chemical plant, and often replaces steel for pump and piston-rods, shafts, cranks, rams, valves, spindles, bolts, nuts, etc. It is supplied in the form of ingots (for casting), billets (from

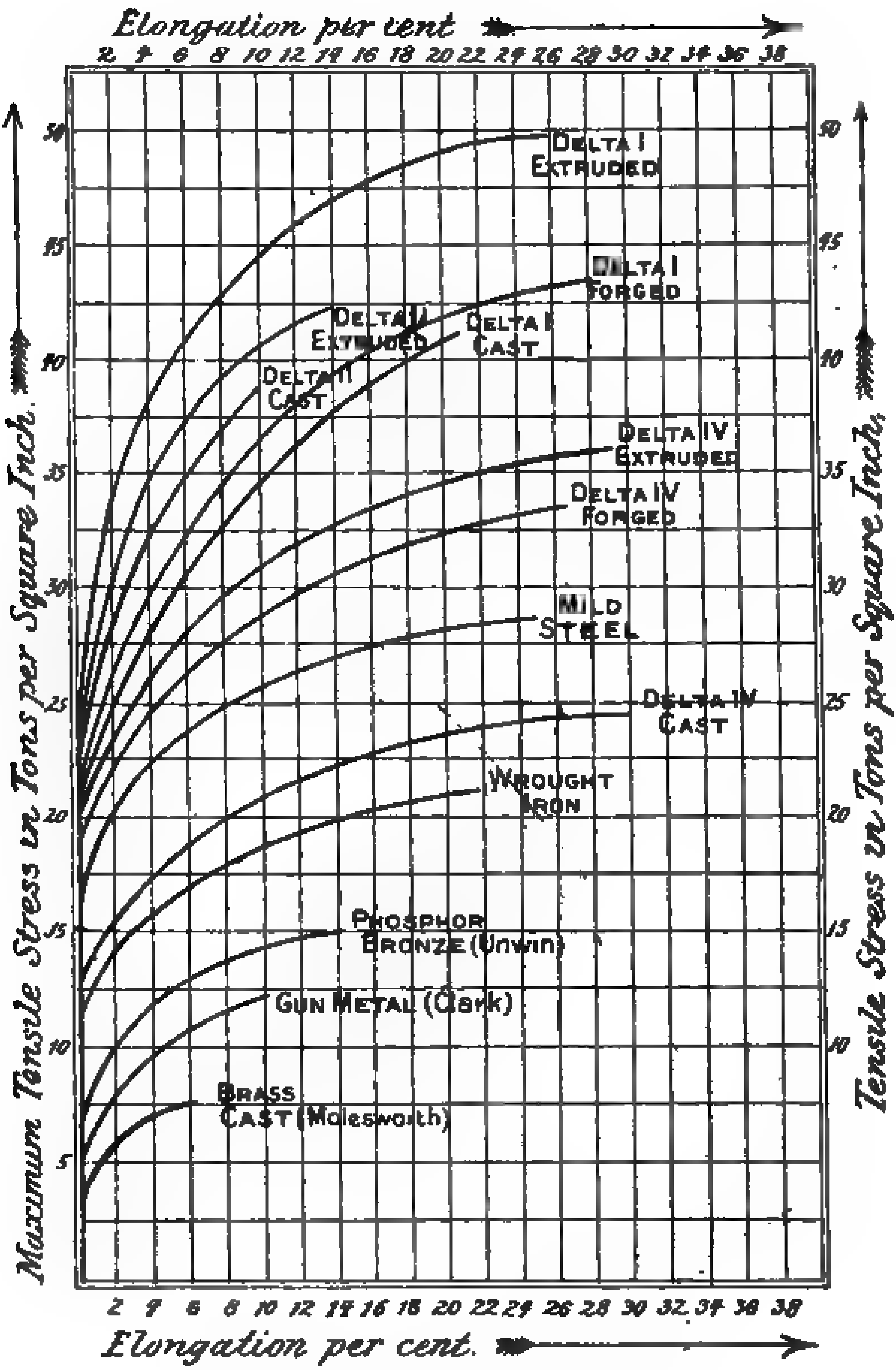

Elongation per cent
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38
Delta I Extruded
Delta I Forged
Delta II Extruded
Delta I Cast
Delta II Cast
Delta IV Extruded
Delta IV Forged
Mild Steel
Delta IV Cast
Wrought Iron
Phosphor Bronze (Unwin)
Gun Metal (Clark)
Brass Cast (Molesworth)
5 10 15 20 25 30 35 40 45 50
Maximum Tensile Stress in Tons per Square Inch.
Tensile Stress in Tons per Square Inch.
Elongation per cent.

Fig. 38.

40 lbs. up to 20 cwts.) for forging, as castings, forgings, or stampings, or as extruded rods, round, square, hexagon, flat, channel, angle, tee, or to any other given section.

The following results refer to tests upon Delta Bronze No. I—

### TABLE LIII.

### Tensile Strength of Delta Bronze No. I.

| *Condition.* | *Area of Specimen, sq. inch.* | *Yield Point.* | *Tensile Strength.* | *Elongation, per cent.* | *Reduction of area, per cent.* |
|---|---|---|---|---|---|
| Cast .. .. | 0·1963 | — | 40·5–41·5 | 23–18 | 24–18 |
| Wrought (forgings) | 0·4417 | — | 42·9 | 28 | — |
| ,, ,, | 0·1104 | — | 43·7 | 25 | — |
| ,, ,, | 0·1963 | — | 43·2 | 29 | — |
| Extruded bar (0·502 inch diameter) | 0·1979 | 24·56 | 49·82 | 26·0 | 24·9 |
| Extruded bar (0·502 inch diameter) | 0·197 | — | 49 | 25 | — |

### TABLE LIV.

### Transverse Bending Test Results With Delta Bronze No. I.

| *Dimensions of Specimen.* | | *Span between supports.* | *Ultimate breaking load at centre* | *Deflection in inches.* |
|---|---|---|---|---|
| *Depth.* | *Breadth.* | | | |
| 1 inch .. | $1\frac{3}{10}$ inch | 12 inches | 8800 lbs. | — |
| 1 ,, .. | $1\frac{1}{8}$ ,, | 12 ,, | 8500 ,, | $1\frac{3}{4}$ inches |

The shearing strength of Delta Bronze No. I in the extruded condition in double shear is given as 23 tons per square inch

## Delta Bronze No. II (Silver Bronze).

This metal is known as " silver bronze " on account of its silver-white colour ; it is malleable and takes a high polish, and is applicable to all kinds of ornamental work requiring a high degree of strength and non-corrosive properties.

This metal resembles German silver in appearance, but is considerably harder and stronger, and it is frequently used in the polish-finished condition in place of nickel-plated fittings.

It is malleable at a dull red heat, and can also be cast in sand and loam, producing clean, sharp castings, close-grained and very strong and tough.

Delta Bronze No. II is specially suitable for ornamental fittings and exposed parts of automobiles, sanitary fittings, instruments, and the like; it can be supplied as ingots, billets, castings, stampings, or forgings, and in the form of rods and bars of any section, such as round, hexagon, channel, bending, stair nosings, fence and lap plate, etc.

The cast metal has a tensile strength of about 38 tons per square inch, with a yield point of about 18 tons per square inch, and an elongation of about 10 per cent. In the extruded condition it has a tensile strength of about 42 tons per square inch, with 14 per cent. elongation and about 7 per cent. reduction of area.

**Delta Bronze No. III.**

This malleable alloy can be worked either hot or cold, and is chiefly used for solid drawn tubes for all hydraulic purposes, for which it is well suited on account of its strength and resistance to corrosion.

These tubes are employed for condensers, and in distilleries, breweries, in general mining work, and wherever the water contains acids or other corrosive substances. Although more expensive than the ordinary brass tubes, they outlast these, and at the same time are capable of withstanding much higher pressures for the same weight.

The results of some hydraulic tests (made by Messrs. Vollot and Badois for French Naval Artillery Dept.) upon one of these tubes of 5·22 inches outside diameter by 0·098 inches thick and 49·21 inches long, showed that with a pressure of 1,400 pounds per square inch there was no measurable enlargement, with 1,850 pounds per square inch the diameter

FIG. 39.
DELTA METAL STAMPINGS AND FORGINGS.

was enlarged permanently by 0·012 inches, and with 2,190 pounds per square inch by 0·015 inches.

**Delta Bronze No. IV.**

This is probably one of the most widely used of the malleable bronzes, owing to its unique strength combined with non-corrosive qualities.

This metal is as strong as the better mild steels, and can be substituted for them in cases in which corrosive action is liable to occur; for this reason it is employed for certain fittings of aeroplanes, especially in the vicinity of compasses.

Delta Bronze No. IV is made in a number of different grades by introducing small quantities of other elements into the standard alloy during the mixing process, so that a variation of the properties in any desired direction is obtainable.

The different grades are distinguished by the addition of a letter to the number of the alloy, such as IV*a*, IV*b*, IV*c*, etc.

Delta Bronze No. IV can be worked both cold and hot; when heated to about 550° C. (or a dull-red colour) it becomes soft and is in the best condition for stamping and forging, and, owing to its semi-plasticity, it does not require much power to transform its shape. Its strength is also appreciably increased by hot working.

This metal is very suitable for die stampings, pressings, and forgings, and very sharp and clean parts may be obtained in large quantities. The compression of the red-hot metal produces a very close-grained structure, entirely free from casting and similar defects, and the sharpness of the impressions is such that little, if any, subsequent machining is necessary.

Figs. 39 and 40 show some typical shapes forged or stamped out of Delta Bronze No. IV.

The stamping and forging processes are also applicable to making parts such as wing-nuts, strainer barrels, brackets, motor fittings, gear and bevel wheels, parts of guns, torpedoes, sewing machines, bicycles, valves for gas cylinders, locks,

Fig. 40.
Delta Metal Stampings and Forgings.

unions, nuts, centrifugal pump impellers, casings, and spindles, and to a large variety of other articles.

**Cast Metal.**

Delta Bronze No. IV can be *cast* equally well in sand or in chill moulds; the metal is melted in plumbago crucibles, or, if in large quantities, in an air-furnace. The molten metal runs freely and produces homogeneous castings, free from blow-holes, and with a fine close grain.

**Casting Instructions.**

The various Delta alloys should on no account be mixed together or with other metals, as this would tend to alter their character.

The sand used for moulding should not be loamy or greasy, but rather loose; if the former, it is advisable to mix it with coal dust—say six parts by volume of sand to one of coal dust. The moulds must be well dried, and the cores thoroughly baked. They must not be coated with plumbago but with lamp-black mixed with water, and not be used until this has thoroughly dried. There should be plenty of vent-holes both in the cores and the moulds.

The shrinking of Delta Metal No. I and No. IV, like that of all dense alloys, is rather more than that of gun-metal or brass, viz., $\frac{3}{16}$ inch per foot, and allowance must be made for this in moulding. The gits and feeders should, therefore, be thicker, and special attention be paid that they are placed at the thickest parts of the casting. Where possible, all corners and angles of the pattern should be rounded or filleted, as for steel castings.

When charging the crucible, enough charcoal to cover the surface of the molten metal 1 inch thick should be added; when the metal is flaring or blowing off it is sufficiently liquid for the purpose, and the crucible should then at once be removed from the fire. Particular attention should be paid to this, so as to avoid overheating the metal.

The molten metal is next stirred thoroughly with an iron

rod and the crucible left standing for one or two minutes, after which the charcoal and any scum floating on the surface is skimmed off. A little borax is then added to protect the surface, the metal is again stirred and skimmed, and then poured quickly into the moulds.

In urgent cases, small castings may be cast green, but it is strongly recommended to dry the moulds wherever it is possible to do so, and for large castings this is absolutely necessary.

When re-casting gits, feeders, or old Delta Metal No. IV, at least an equal proportion of new metal of the same alloy should be added.

The strength of the cast metal is shown in the following table—

TABLE LV.

STRENGTH OF CAST DELTA BRONZE NO. IV.

| *Condition.* | *Elastic Limit, tons per sq. inch.* | *Tensile Strength, tons per sq. inch.* | *Elongation on 2 inches per cent.* |
|---|---|---|---|
| Sand cast (machined) .. | 11·54 | 23·89 | 21 |
| Cast worm wheels (locomotive) | — | 21–23·5 | 40–30 on 7 inches |
| Chill cast bar (means) .. | 19·02 | 26·85 | 36·88 |
| Cast pinion wheels .. .. | — | 23·3–23·86 | 40–30 on 7 inches |

The following are the results of a torsional test upon cast Delta Bronze No. IV—

TABLE LVI.

TORSIONAL TEST UPON CAST DELTA BRONZE NO. IV.

(Kirkaldy.)

Length of Lever .. 12 inches. Length of Torsion .. 8 diameters

| *Dimensions.* | | *Stress.* | | *Ratio of elastic to ultimate. Per cent.* | *Torsion 500 lbs. on each end. 1 Turn = 1·0* | *Ultimate. 1 Turn = 1·0* |
|---|---|---|---|---|---|---|
| *Diameter. Inches.* | *Area, square inch.* | *Elastic on each end. lbs.* | *Ultimate on each end. lbs.* | | | |
| 1·128 | 1·000 | 345 | 1042 | 33·1 | 0·194 | 1·372<br>1·436 |

The following results refer to the forged and extruded conditions—

## TABLE LVII.

### Strength of Forged and Extruded Delta Bronze No. IV.

| *Condition.* | *Tensile Strength, tons per sq. inch* | *Elongation per cent.* | *Reduction of area.* |
|---|---|---|---|
| Valve spindle forged from 0·506 inch diameter down to 0·201 inches .. .. | 35·07 | 30·0 | — |
| Forged 1 inch bar (mean of four results) .. .. | 34·4 | 26·25 | — |
| Extruded ⅞ inch bar (mean of six results) .. .. | 36·4 | 29 | — |
| Extruded bars, ⅞ inch diameter | 37·1 | 27·0 | 20 |

The crushing strength of a specimen from an extruded bar measuring 0·5 inch diameter and 1 inch long was 65·85 tons per square inch.

The shearing strength, in double shear, for an extruded bar, was 18·46 tons per square inch, or 9·23 tons per square inch in the single shear.

The strength of Delta Bronze No. IV does not appear to be very appreciably affected by temperature increase up to about 500° F., and it shows only about one-half of the decrement in strength of other non-ferrous metals such as brass, gun-metal, and phosphor-bronze.

The following results were obtained by Professor Unwin—

## TABLE LVIII.

### Temperature Effect upon the Strength of Delta Bronze No. IV.

*A.* Cast Metal.

| *Temperature, ° Fah.* | *Tensile Strength in tons per sq. inch.* | *Elongation per cent. in 2 inches.* | *Reduction of area per cent.* |
|---|---|---|---|
| Atmospheric | 20·15 | 4·5 | 6·3 |
| Atmospheric | 18·25 | 4·0 | 7·0 |
| 310 | 23·36 | 7·0 | 11·8 |
| 410 | 22·48 | 9·0 | 13·0 |
| 506 | 19·68 | 16·0 | 22·3 |
| 590 | 16·00 | 4·0 | 9·4 |
| 635 | 12·70 | 45·0 | 45·7 |

*B.* ROLLED METAL.

| *Temperature, ° Fah.* | *Tensile Strength in tons per sq. inch.* | *Elongation per cent. in 2 inches.* | *Reduction of area per cent.* |
|---|---|---|---|
| Atmospheric | 31·16 | 20·0 | 55·0 |
| 260 | 28·30 | 22·0 | 47·0 |
| 400 | 26·58 | 25·0 | 53·0 |
| 500 | 23·83 | 27·9 | 59·0 |
| 570 | 19·32 | 38·5 | 60·0 |
| 670 (about) | 16·04 | 33·0 | 48·0 |

## Delta Bronze No. IV.—Wire.

Delta Bronze No. IV can be drawn out into wire; when annealed, the tensile strength is from 35 to 40 tons per square inch with about 30 to 25 per cent. elongation, but by drawing hard, the strength may be raised to over 50 tons per square inch, with a corresponding reduction in the elongation.

When the hard-drawn wire is heated in melting tin (230° C.) the tensile strength is from 48 to 52 tons per square inch, with an elongation of from 9 to 11·5 per cent.

This wire is suitable for binding or strengthening parts subjected to high temperatures, such as steam and exhaust pipes, as it does not lose its strength so quickly as other bronze, brass, or copper wires.

## Applications of Delta Bronze No. IV.

Apart from the examples previously mentioned, this alloy is used on a large scale for the plates of hulls of launches, yachts, pinnaces, and other vessels exposed to sea-water corrosive action, for, apart from its greater strength than steel, it gives a smooth surface, which is not affected by salt water action, and it is non-magnetic. Delta Bronze No. IV is also used for ship frames, forgings, castings, angles, deck and keel bolts, etc.

It is also suitable for all kinds of electrical work, in which the use of a strong non-magnetic metal is required. It can be cast in the form of rotor-rings and other parts.

The metal is supplied in the form of rolled sheets, plain, perforated, corrugated, ribbed, flanged, etc., rolled, drawn, or extruded bars of all sections, solid drawn tubes of various sizes and sections, drawn wire, ingots for casting (weight about 14 pounds), billets (round chill-cast ingots) for forging, rolling, and stamping hot.

**Aeronautical Specifications.**

Delta Bronze No. IV is supplied for non-rusting, highly stressed parts, such as brackets, control fittings, control arms, pulleys, etc.

It is usual to specify a minimum yield point of about 20 tons per square inch, with a tensile strength of from 27 to 33 tons per square inch, the lower values corresponding to the larger sizes of forgings. The elongation and reduction of area should not be less than 25 and 50 per cent. respectively.

A bend test is also specified, namely, that bars up to ¾ inch diameter should be capable of withstanding being bent over through an angle of 180° until the internal radius of the bend is equal to 1½ times the diameter of the test piece, without developing cracks or flaws.

Delta Bronze for non-corrosive tubing should have a yield point of from 17 to 20 tons per square inch, with a tensile strength of from 24 to 28 tons per square inch.

A crushing test should be specified as follows, namely, that a piece of the tubing of length equal to its external diameter shall withstand crushing until its length is reduced to one-half of its original value, without cracking or developing surface flaws.

## R.A.E. Specification for Delta Metal (or Equivalent Alloy) Tubes.

1. Application.—For parts which require to be non-rusting.

2. Tubes.—The tubes are to be of the weldless solid drawn type, manufactured only from the best material.

3. All tubes must be sound, straight, well finished, and free from all

surface defects. They are to be uniform in quality and capable of being machined easily in order to leave a good finish.

4. Tubes are to be supplied in bundles, and each bundle is to consist only of tubes made from one cast, and every bundle is to be distinguished by its own registered number. This number is to be clearly stated in all correspondence and bills relating thereto.

5. SIZE.—All tubes are to be of uniform thickness and diameter, and are to agree accurately with the dimensions specified. A limit of plus or minus ·6 per cent. of the external diameter of the tube will be tolerated on the external diameter for all sizes of tubing, while a variation of plus or minus 5 per cent. of the tube thickness respectively will be tolerated on all thicknesses of tube.

6. TESTS.—Test pieces taken from any tube are to comply with the following mechanical tests—

(*a*) *Tensile Test.*—

| | |
|---|---|
| Ultimate stress .. .. .. .. | 25 tons per square inch. |
| Yield point .. .. .. .. | 18 ,, ,, ,, |

The tensile tests will be performed on pieces of complete tube.

(*b*) *Crushing Test.*—A complete section of tubing 1 inch long is to stand being crushed until its length is diminished by half, without splitting or developing cracks on the interior or exterior surfaces.

7. The above test values are minima. If any one of the test pieces fails to pass the specified tests, the tube or tubes represented by the defective specimen will be rejected.

8. No test piece will be annealed, hammered, or otherwise treated after its removal from the tube.

9. The manufacturer must bear the cost of depreciation in value of any rejected materials due to test pieces being cut therefrom.

10. Test pieces, when submitted, must not be less than 10 inches long.

## R.A.E. SPECIFICATION FOR DELTA METAL IV*e* (OR EQUIVALENT ALLOY) IN THE FORM OF FORGINGS OR STAMPINGS.

APPLICATION.—For parts which require to be non-rusting and which are fairly high stressed.

FORGINGS AND STAMPINGS.—All forgings or stampings are to be sound, free from cracks, and coarse grain. No attempt is to be made to repair defects by patching, burning, or welding.

MACHINING ALLOWANCES.—1. Such allowances are to be left on the forgings or stampings, where machining is indicated, in order that the machinist can produce the finished parts to the required dimensions.

2. The forging or stamping dimensions not necessitating machining must be quite accurate to the drawing.

3. MACHINING (If parts are supplied in machined condition).—If requested, the contractor must submit a sample of the work to R.A.E. for approval before proceeding with the order.

Where definite limits are indicated, representing the degree of accuracy to which parts are to be manufactured, the Newall system is implied (unless otherwise stated).

TESTS.—Test specimens taken from any forging, or from any bar

used in the manufacture of the stampings, are to comply with the following mechanical tests—

(*a*) *Tensile Test.*—

| | *Bars under ½ inch diameter.* | *Bars ½ inch diameter and over.* |
|---|---|---|
| Ultimate stress .. | 32 tons per sq. inch | 28 tons per sq. inch |
| Yield point .. .. | 20 „ „ | 20 „ „ |
| Elongation on 2 inches | 25 per cent. | 25 per cent. |
| Reduction of area .. | 50 „ | 50 „ |

The tensile test is to be made on the British Standard Test piece (·564 inch diameter × 2 inches acting length) or on a specimen which has the same geometrical proportions.

(*b*) *Bending Test.*—A bend test piece of the original diameter up to ¾ inch diameter, or machined down to that size from bars over ¾ inch diameter, is to be taken and must withstand, without fracture or the developing of cracks, being doubled over through an angle of 180° until the internal radius is equal to one and one-half times (1½) the diameter of the test piece and the sides are parallel.

2. The above test values are minima. If any one of the test pieces fails to pass the specified tests, the forgings or stampings represented by the defective specimen will be rejected.

3. Test pieces must be left on the forgings where required, and after removal from the forgings these pieces are not to be hammered or otherwise treated.

4. Test pieces taken from the material used in the manufacture of the stampings are to be supplied for testing purposes.

5. The manufacturer must replace, free of charge, all material consumed in testing and found to be defective.

## R.A.E. Specification for Delta Metal IV*e* (or Equivalent Alloy) in Form of Bar.

Application.—For parts which require to be non-rusting and which are fairly highly stressed, such as turn-buckles, bolts, nuts, etc.

Bars.—1. Bars as supplied by the manufacturer are not to be heated in any way before, during, or after machining.

2. The bars are to be sound, straight, free from twists, seams, and damaged ends and must have a workmanlike finish. They are to be uniform in quality and capable of being machined easily and of taking a good finish.

3. The sizes of the bars are to be within the margin of manufacture as laid down by the E.S C. in their Report, No. 32 (May, 1907), pp. 9 and 10.

4. Bars are to be supplied in bundles, and each bundle is to consist only of bars made from one cast, and every bundle is to be distinguished by its own registered number. This number is to be clearly stated in all correspondence and bills relating thereto.

Each cast is not to exceed ½ cwt. for bars under ½ inch diameter; 1 cwt. for bars of ½ inch to under 1 inch diameter; and 2 cwts. for bars of 1 inch diameter and over.

TESTS.—1. Two test specimens are to be taken from each bundle of bars as representing one cast, one for tensile, and one for bending test, and these are to comply with the following mechanical tests—

(*a*) *Tensile Test.*—

| | *Bars under ½ inch diameter.* | *Bars ½ inch diameter and over.* |
|---|---|---|
| Ultimate stress .. | 32 tons per sq. inch | 28 tons per sq. inch |
| Yield point .. .. | 20 ,, ,, | 20 ,, ,, |
| Elongation on 2 inches | 25 per cent | 25 per cent. |
| Reduction of area .. | 50 ,, | 50 ,, |

The tensile test is to be made on the British Standard Test piece (·564 inch diameter × 2 inch acting length), or on a specimen which has the same geometrical proportions.

(*b*) *Bending Test.*—A bend test piece of the original diameter up to ¾ inch diameter or machined down to that size from bars over ¾ inch diameter, is to be taken and must withstand without fracture or the developing of cracks in its outer or inner angle surface, being doubled over through an angle of 180° until the internal radius is equal to one and one-half (1½) times the diameter of the test piece and the sides are parallel.

2. These test values are minima. If any one of the test pieces fails to fulfil any one of these tests, the whole bundle of bars from which the test piece was taken will be rejected.

3. No test piece will be annealed, hammered, or otherwise treated after its removal from the bar.

4. The manufacturer must replace free of charge all material consumed in testing and found to be defective.

## THE EXTRUSION PROCESS*

This process, which enables rods of any section to be obtained in long lengths, consists in forcing the hot plastic metal under pressure through a die of similar cross-section to that required, the heated billet being forced through the die by a pusher rod carried by a hydraulic ram.

This process was initially attended by many difficulties in connexion with the maintenance of the metal at the high temperature necessary for the extension, and in making the pressure cylinders and dies strong enough to withstand both the high temperature and pressure.

* Invented by Mr. Dick about 1888, and subsequently developed by the Delta Metal Co. See also "The Extrusion Process." H. Rawson. Paper read before the Liverpool Engineering Society, March, 1919.

The billets are now enclosed in containers, which keep them at the correct temperature.

The metal, which is usually a copper alloy, must be kept below its fusion temperature, otherwise it will flow like a liquid through the dies, and will neither be straight nor of the correct die-section upon cooling.

On the other hand, if it is too plastic, the compression required to force it through the die will not cause sufficient work to be done on it to give the necessary strength.

If the temperature is not high enough, the metal will simply spread in the container and will not extrude properly.

**Dies.**

The dies through which the metal is forced are made of a high grade tungsten steel, and they are curved at the entrance to approach as nearly as possible the streamline formation of the flowing metal; the narrowest section of the die should be approached tangentially and should be constant over a small distance, depending upon the diameter of the rod to be extruded, and then backed away more rapidly.

The diameter of the die must be larger than that of the rod to be extruded; for rods of diameters 1 to 2½ inches it has been found that the ratio of the rod to die diameter is about 0·94, whilst for smaller sizes it may be as much as 0·97.

In addition to the *vena-contracta* effect, which necessitates the use of larger dies, there is also the contraction due to cooling. Contrary to expectations, the dies do not increase in diameter due to continuous use, but actually decrease, owing to the flow of the die-metal towards the throat under the influence of the high pressures and temperatures used.

**Presses.**

A 600 ton press,* capable of dealing with billets 5¼ inches diameter and 2 feet long, and of producing extruding bars up to 2½ inches diameter, will produce a bar 2 inches diameter,

* Fielding and Platt type.

about 11½ feet long, or one of 1 inch diameter 46 feet long. This size of press will deal with 20 to 25 billets per hour.

### Containers.

The original type of container invented by Mr. A. Dick was provided with a passage in its casing through which the flames from a coke fire passed; this form is still employed in improved forms.

The electrically heated type of container is finding much favour on account of the ease with which the heat can be regulated. The billets, before entering the container, are pre-heated in a reverberatory or similar furnace.

Some containers are cast hollow, the space being filled with glass, sand, asbestos, or similar material. Others are built up with alternate cylindrical discs of steel and asbestos, the billet being enclosed in a cylinder, which is tapered on its outer circumference to fit a tapered hole in the built up container. In this manner the heat is prevented from penetrating the cylinder walls, so that the container is kept at a lower temperature and is thus better enabled to withstand higher temperatures and pressures.

### Sections.

Fig. 41 shows some typical extruded sections, which will be seen to include circular, hexagonal, channel, angle, flat, tee, various beading sections, and pinion wheel sections; the weights of the extruded sections in copper alloys vary from a few ounces to 40 pounds per foot run.

The metals that can be extruded include copper, brass, aluminium, manganese, and aluminium bronzes, Delta metals Nos. I to IV, and similar alloys.

## MISCELLANEOUS COPPER ALLOYS

The following copper alloys with manganese, zinc, and nickel, were tested by Dr. Rosenhain, but were cast with the aid of borax alone, in the ordinary manner.

Fig. 41.

Fig. 41.

## TABLE LIX.

### PROPERTIES OF MISCELLANEOUS COPPER ALLOYS.

| *Composition.* Copper | Mang. | Zinc. | Nickel. | Lead. | *Condition.* | *Yield Point, tons per sq. inch* | *Tensile Strength, tons per sq. inch.* | *Elongation in 2 inches per cent.* |
|---|---|---|---|---|---|---|---|---|
| 95·5 | 4 | — | — | 0·5 | As rolled | 30 (?) | 38 | 4·5 |
| | | | | | Annealed* | 11 | 21 | 35 |
| 88 | 2 | 10 | — | — | As rolled | 35 | 37 | 5·0 |
| | | | | | Annealed* | 8 | 21 | 41·5 |
| 87 | 3 | 10 | — | — | As rolled | 42 | 47 | 3·0 |
| | | | | | Annealed* | 11 | 23 | 35 |
| 85 | — | 5 | 10 | — | As rolled | 31 | 34 | — |
| | | | | | Annealed* | 8 | 20 | — |
| 88 | — | 7 | 5 | — | As rolled | 27·5 | 32·5 | — |
| | | | | | Annealed* | 7 | 19 | 10·5 |
| 80 | — | 10 | 10 | — | As rolled | 35 (?) | 39 | 3 |
| | | | | | Annealed* | 10 | 21 | 35 |

* Annealed at 650° C. for 30 minutes.

## CHAPTER III

# BEARING METALS, Etc.

### BEARING METALS

There are two types of bearing metals employed in practice, namely—

(*a*) Alloys such as gun-metal, phosphor-bronze, and copper alloys of a fairly hard nature, and consisting of hard constituents in a softer matrix.

(*b*) Alloys, such as white-metal, babbitt-metal, and similar lead or tin-base metals of a softer nature, consisting of hard crystallites in a softer eutectic alloy matrix.

The class (*a*) group of metals have already been considered under the headings of copper-tin alloys, gun-metal, and phosphor-bronze. The principal constituent of these bearing metals is copper, and the other constituents include tin, lead, phosphorus, manganese, iron, and zinc.

The tensile strengths of the bronzes vary from 15 to 40 tons per square inch.

The Brinell hardness numbers vary from about 70 to 200, according to the constituents present and the processes employed; the chill-cast and mechanically treated alloys give the higher values.

### BEARING PRESSURES

The allowable working pressures upon the bearings depend upon several factors, such as the nature of the lubricant, the system of lubrication, the nature of the motion (that is, whether sliding, rolling, reciprocating, etc.), and the rate of rubbing, so that it is difficult to state generally the correct bearing pressures for the bronze group of bearing alloys.

It may, however, be mentioned that for slow speeds and reciprocating sliding motions, such as in the case of the

cross-heads of steam engines, bearing pressures up to 2000 pounds per square inch have been used. In general, the higher the speed the lower is the permissible bearing pressure.

For rotational speeds of from 100 to 500 revolutions per minute, with shafts up to 9 inches diameter, the working bearing pressures vary from 500 to 2000 pounds per square inch.

For high rotational speeds similar to those occurring in petrol engine practice, bearing pressures of from 400 to 1800 pounds per square inch (in the case of motor cycle engines) have been employed.

For example, in the case of the Liberty 400 h.p. aircraft engine, the following are the values of the bearing pressures—

| *Component.* | *Bearing Pressure in lbs. per sq. in.* | |
|---|---|---|
| | *Maximum.* | *Mean.* |
| Centre Main Bearing .. .. | 1,675 | 1,265 |
| Intermediate Main Bearing .. | 1,580 | 700 |
| End Main Bearing .. .. | 815 | 610 |
| Crank Pin Bearing .. .. | 932 | 642 |

The coefficient of friction for normally loaded bronze bearings* dry varies from 0·14 to 0·20, whilst for properly lubricated bearings, with steel shafts, it varies from ·03 to ·08.

A good hard-bearing metal should not only possess a low coefficient of friction, combined with sufficient strength, but it should be a good conductor of heat, and it should wear at a very slow rate; it has been shown that the harder the bearing metal the more liable it is to heat up.

It is also essential that the bearing metal should cast well, giving sharp sound castings free from blow-holes or other defects. The alloys recommended for high-class aeronautical and automobile work are phosphor-bronze, gun-metal, tobin-bronze, manganese-bronze, aluminium-bronze, Delta I and

* For fuller information, the reader is referred to "Elements of Machine Design," W. C. Unwin, pp. 227–257.

IV and VI to VIII metals, and certain of the copper-tin alloys.

It is not usual to employ hard bearing metals in the shape of intricate and expensive bearing castings, on account of the expense entailed in replacing worn bearings, but rather to utilize these metals in the form of bushes, or bearings which can be re-bushed without trouble.

The following resu'ts refer to the rates of wear of different bearing metals—

TABLE LX.

Wear of Bearings. (Thurston.)

| *Metal.* | *Composition.* | | | *Miles run per lb.* | *Wear per 100 miles for 4 bearings. (7000 grains = 1 pound.)* |
|---|---|---|---|---|---|
| | *Copper* | *Tin* | *Anti-mony.* | | |
| Gun-metal .. .. | 83 | 17 | — | 25,489 | 200 grains |
| " .. .. | 82 | 18 | — | 27,918 | 252 " |
| White-metal (Babbitt) | 3 | 90 | 7 | 22,075 | 366 " |
| " " | 5 | 85 | 10 | 24,857 | 284 " |
| Lead composition .. (Lead 84; antimony 16) | — | — | 16 | 22,921 | 308 " |
| Gun-metal (Brakes) | 82 | 18 | — | 2,576 | 274 " |

Experiments were conducted some time ago upon the Pennsylvania railroad, on the subject of the relative wear of hard bearing metals. A certain bearing metal was made into the form of a bearing and placed upon one side of the ax!e of a car, whilst various experimental bearings were placed upon the other side of the axle of the car. Before and after the car had run for a considerable period, the bearings were weighed, and the wear, as measured by the difference between the initial and final weights, of the bearings was compared with that of the standard bearing material, which was taken as being 100.

The loss in weight of the standard material was 1 pound

per 18,000 to 25,000 miles. The following are the results of some of the tests—

## TABLE LXI.

### Relative Wear of Different Bearing Metals.

| *Metal.* | *Percentage composition.* | | | | | *Rate of Wear.* |
|---|---|---|---|---|---|---|
| | *Copper* | *Tin* | *Lead* | *Phosphorus* | *Arsenic* | |
| Standard metal | 79·70 | 10·00 | 9·50 | 0·80 | — | 100 |
| Copper-tin .. | 87·50 | 12·50 | — | — | — | 148 |
| " " .. | 87·50 | 12·50 | — | — | — | 153 |
| " " .. | 87·50 | 12·50 | — | — | — | 147 |
| Arsenic bronze.. | 89·20 | 10·00 | — | — | 0·80 | 142 |
| " " .. | 79·20 | 10·00 | 7·00 | — | 0·80 | 115 |
| " " .. | 79·70 | 10·00 | 9·50 | — | 0·80 | 101 |
| "K" bronze .. | 77·00 | 10·50 | 12·50 | — | — | 92 |
| " " .. | 77·00 | 10·50 | 12·50 | — | — | 92·7 |
| Alloy "B" .. | 77·00 | 8·00 | 15·00 | — | — | 86·5 |

It was found that the copper-tin (70 : 10) bearing metal was distinctly inferior to the phosphor-bronze metal, and that it heated up much quicker; the latter metal was initially adopted as the standard bearing metal as a result of the above tests. The alloy designated "K" bronze was also found to be a satisfactory bearing metal, as it wore about 7·3 per cent. slower, and did not heat up any more than the phosphor-bronze.

The "B" alloy metal was eventually adopted as the standard metal, as it wore 13·5 per cent. slower than the phosphor-bronze and did not heat up appreciably under the ordinary running conditions; moreover it is a cheaper metal to employ.

The following is the composition of a suitable alloy which possesses about the same wearing properties as that of the "B" alloy: Copper, 105 pounds; phosphor-bronze, 60 pounds; tin, 9·75 pounds; lead, 25·25 pounds. If the metal is melted with a covering of charcoal no trouble is experienced in obtaining sound castings.

## PLASTIC OR LEAD BRONZES

Bearing metals composed of copper, tin, and lead are known as " plastic bronzes " ; an example of the composition of a typical alloy is given upon p. 103, and the compositions of most of the bronzes in the preceding paragraph show that they really belong to this class.

It has been found that the lead does not alloy with the bronze but separates out of the molten metal, as it cools, in the form of globules, so that the final structure consists of a network of bronze alloy enclosing the lead content within its meshes.

Subsequently to the results mentioned in the preceding paragraph, relating to the " B " alloy bearing metal, it was found that the expensive tin content could be diminished, and the lead increased considerably, without any deterioration in the bearing properties.

A satisfactory alloy of this class has the following composition, namely—

| | Per cent. |
|---|---|
| Copper .. .. .. .. .. | 65 |
| Lead .. .. .. .. .. | 30 |
| Tin .. .. .. .. .. | 5 |

The compressive strength of the metal is about 7 tons per square inch, and it is found to be particularly suitable for the driving, connecting rod, and other bearings of locomotives.

The following are the ranges of compositions of the plastic bronzes employed commercially—

| | Per cent. |
|---|---|
| Copper .. .. .. .. | 65–75 |
| Lead .. .. .. .. | 10–30 |
| Zinc .. .. .. .. | 0–20 |
| Tin .. .. .. .. .. | 2–10 |

## THE SOFTER BEARING METALS

This class of bearing metals consists of fairly soft and fusible alloys having either a tin or lead base, and containing smaller quantities of other metals, such as antimony, copper, or zinc.

The tin-base metals include the Babbitt, Magnolia, Ajax, Hoyt, and other well-known bearing alloys. The lead-base metals include lead-antimony alloys, certain of the Babbitt metals, type-metal, and other white metals.

The advantage of the tin-base metals lies in the fact that the oleic acid present in some lubricants does not attack the tin, as in the case of zinc and lead.

It has been observed that, in general, those metals which give a high value for the ratio of the atomic weight to the specific gravity are the best anti-friction metals; thus, lead, tin, and antimony are appropriate for this reason.

Most of the tin or lead-base alloys contain a small proportion of hardening metals such as antimony, copper, or bismuth; the Brinell hardness of a good soft bearing metal* should not be less than about 20.

The softer type of bearing metal is not used alone, in the form of a bearing, on account of its low tensile and compressive strengths, but is used in the form of a thin lining in main shells or bearings of brass, bronze, or steel; the advantages of this practice are that the metal can be readily run into position around a mandrel, so that little or no subsequent machining or work is required, beyond scraping in, and that worn bearings can be easily re-run.

Particulars of the methods of lining bearings are given on p. 160.

## Structure of Softer Bearing Metals.

The subject of the structure of special alloys for bearings or anti-friction metals has been studied at some length by M. Charpy†, Behrens, and others. The former investigators found that in the case of alloys of tin, antimony, and copper, they all consist of hard grains embedded in a plastic matrix.

* Values for pure lead-tin alloys are given on p. 154.

† Das "Mikroscopische Gefuge von Metallen und zegierungen," 1894; p. 60.

Fig. 42 illustrates the micro-structure of a typical automobile white-metal consisting of—

| | Per cent. |
|---|---|
| Copper .. .. .. .. .. | 10 |
| Tin .. .. .. .. .. | 78 |
| Antimony .. .. .. .. | 12 |

The hard tin-antimony cubes are clearly shown, embedded in the softer matrix. It is believed that the cubic crystals

FIG. 42.—SHOWING STRUCTURE OF TYPICAL BEARING METAL. MAGNIFIED 26 TIMES.

correspond to the chemical formula Sb.Sn or $Sb.Sn_2$, and that the star-like crystals which sometimes occur consist of $Sb.Cu_2$ or $Sb.Cu_3$, that is to say, a compound of tin and copper. (Fig 43.)*

The softer matrix in which the hard crystals are embedded consists of an eutectic containing all three of the metals. In order to find out what actually occurs during the wearing of an alloy, it is only necessary† to polish the alloy without etching it; the result of such a procedure is to show the hard antimony-tin, or copper-tin, crystals in relief, as illustrated in Fig. 44. It is thought that the load is carried by

* "Bulletin de la Société d'Encouragement pour l'Industrie Nationale," June, 1898.
† Charpy.

the hard grains, which have a low coefficient of friction and are not easily subjected to the accidents known as " hot-box " and " cutting," when there is an abrupt and considerable increase in the coefficient of friction.

FIG. 43.—SHOWING THE EFFECT OF WEAR IN WHITE METAL.

FIG. 44.—SHOWING THE STRUCTURE OF WHITE METAL.

When an axle is placed in a new bearing, however, contact between the two only occurs at a limited number of points, and if the axle and bearing are both hard and unyielding heating rapidly ensues. To avoid this and to allow for

irregular wear, and also for irregularities of adjustment in erecting a shaft carried by several bearings, the matrix of the anti-friction metal must be soft and plastic, so as to mould itself to the axle during the running and yet be strong enough to carry the load without permanent distortion.

The lead-antimony alloys containing less than 13 per cent. of antimony are found to consist of crystallites of lead embedded in an eutectic lead-antimony alloy, whilst those containing more than 13 per cent. of antimony consist of crystallites of antimony embedded in an eutectic lead-antimony alloy. In either case the crystallites are harder than the matrix.

It has been suggested by Behrens and Baucke* that the star-like crystals of copper and tin in this class of anti-friction metal are too brittle to stand much pressure, and they therefore crumble, but that the fragments worn off are largely spheroid in shape, consisting of worn cubes of antimony and tin; and these, mixing with the oil, form a *ball cushion*, so that a rolling instead of a sliding friction occurs.

**Composition of Tin-base Alloys.**

The following table gives the compositions and applications of the more reliable metals employed in practice, and in which *tin* is the principal constituent.

The Babbitt metals are white-metals containing tin, copper, antimony, and lead; the various commercial Babbitts vary considerably in composition, the cheaper ones containing a minimum of tin and a maximum of lead.

The American Society for Testing Materials reduces the large number of existing Babbitts down to five standard compositions, each of which is intended for a specific purpose; these Babbitts are given in Table 62.

It may be mentioned that the true Babbitt metal†, which was the first white-metal successfully used, was composed of 80 per cent. tin, 10 per cent. copper, and 10 per cent. antimony.

* "Metallographist," 1900, p. 4.
† Introduced by Isaac Babbitt.

## TABLE LXII.

### Composition of Tin-Base Anti-Friction Metals.

| *Name.* | *Composition, per cent.* | | | | | *Remarks.* |
|---|---|---|---|---|---|---|
| | *Tin.* | *Copper* | *Antimony.* | *Lead.* | *Bismuth.* | |
| Original Babbitt .. | 80 | 10 | 10 | — | — | — |
| Babbitt No. 1 .. | 83⅓ | 8⅓ | 8⅓ | — | — | Amer. Soc. for Testing Materials Specns. |
| " " 2 .. | 89 | 4 | 7 | — | — | For high speed, high pressure bearings. |
| " " 3 .. | 50 | 2 | 15 | 33 | — | For medium pressures and fast speeds. |
| " " 4* .. | 5 | — | 15 | 80 | — | For medium pressures and low speeds |
| " " 5* .. | — | — | 10 | 90 | — | For low pressures and speeds, such as shaftings |
| U.S. Navy White-metal Specification .. | 88·8† | 3·7 | 7·5‡ | — | — | — |
| International Aircraft Standard Specification | 90–92 | 4–5 | 4–5 | — | — | Specification 3N.10 for aerò engines |
| Daimler Motor Bus White-metal .. | 78 | 10 | 12 | — | — | *Engineering*, 17 Jan.'13 |
| Admiralty White-metal | 86 | 5·5 | 8·5 | — | — | — |
| Good White-metal .. | 83·3 | 5·55 | 11·12 | — | — | Used on French railroads for axles and connecting rods |
| Ajax Metal .. .. | 11·5 | 77 | — | 11·5 | — | Ditto. |
| Richards White-metal | 70·0 | 4·5 | 15·0 | 10·5 | — | Plastic white-metal for aero engine bearings, etc. |
| Britannia Metal .. | 85·7 | 1·0 | 10·1 | *Zinc*, 2·9 | — | For stop-cock seatings |
| " " .. | 81·0 | 2·0 | 16·1 | *Zinc*, 1·0 | — | " " plugs |
| " " .. | 70·5 | 4·0 | 25·5 | — | — | For bearings |
| " " .. | 22·0 | 10·0 | 62·0 | *Zinc*, 6·0 | — | — |
| Plate Pewter .. | 89·3 | 1·8 | 7·1 | — | 1·8 | — |

The effect of *antimony* in lead-tin alloys is to increase the hardness, whilst *tin* increases the toughness when added to lead.

When more than about 18 per cent. of antimony is present the plasticity of the white-metal is seriously reduced, and the metal is rendered brittle.

Bearings subjected to heavy pressures require high percentages of antimony, whilst those carrying light loads require only small percentages of antimony.

Metals containing high tin content have a low fusion point, as a rule, and are expensive.

Figs. 45 and 46 show the properties of lead-tin alloys. It will

* These lead-base metals are included to complete the series.
† Banca tin.
‡ Regulus of Antimony.

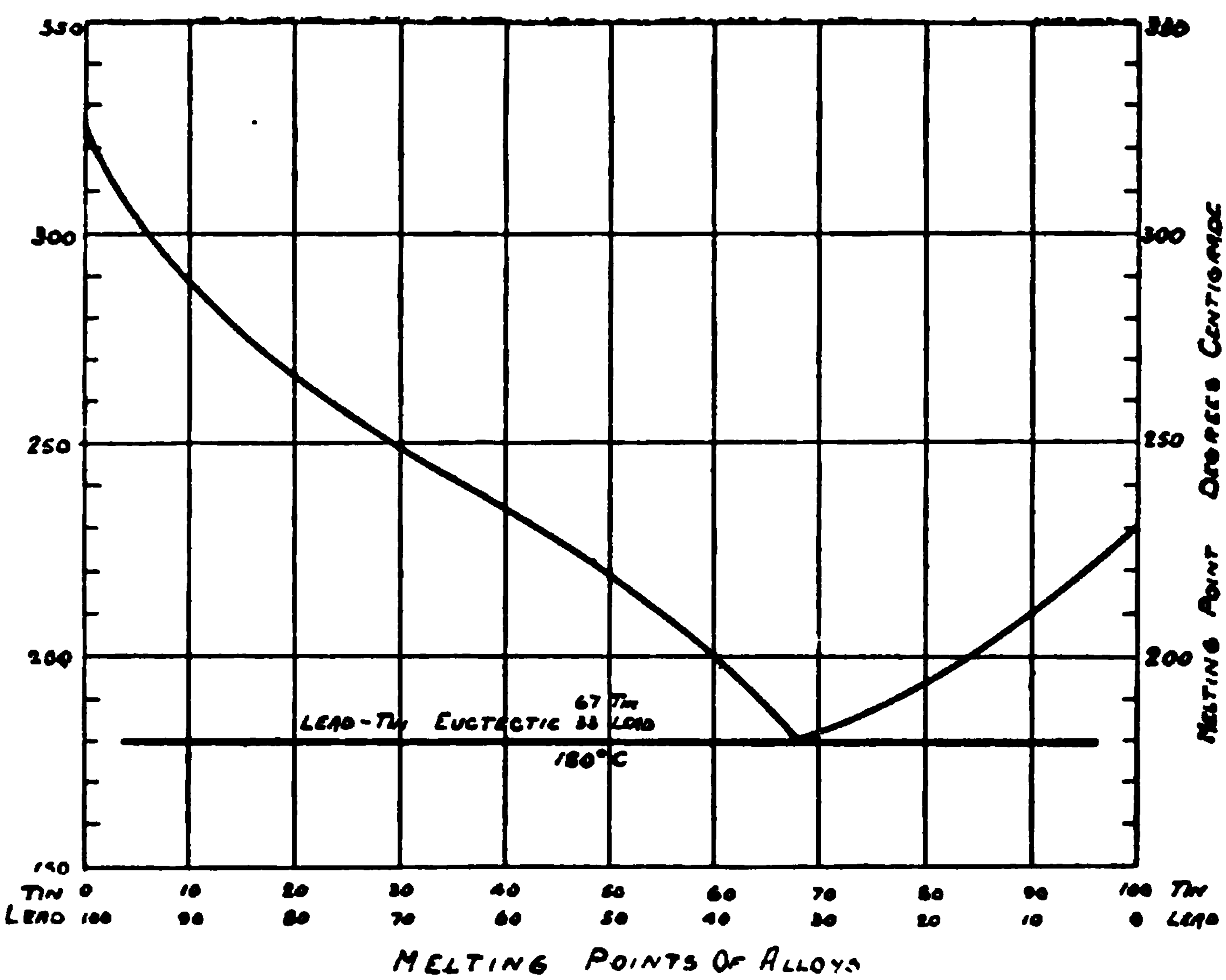



Fig. 45.—Cooling Curves for Lead-Tin Alloys.

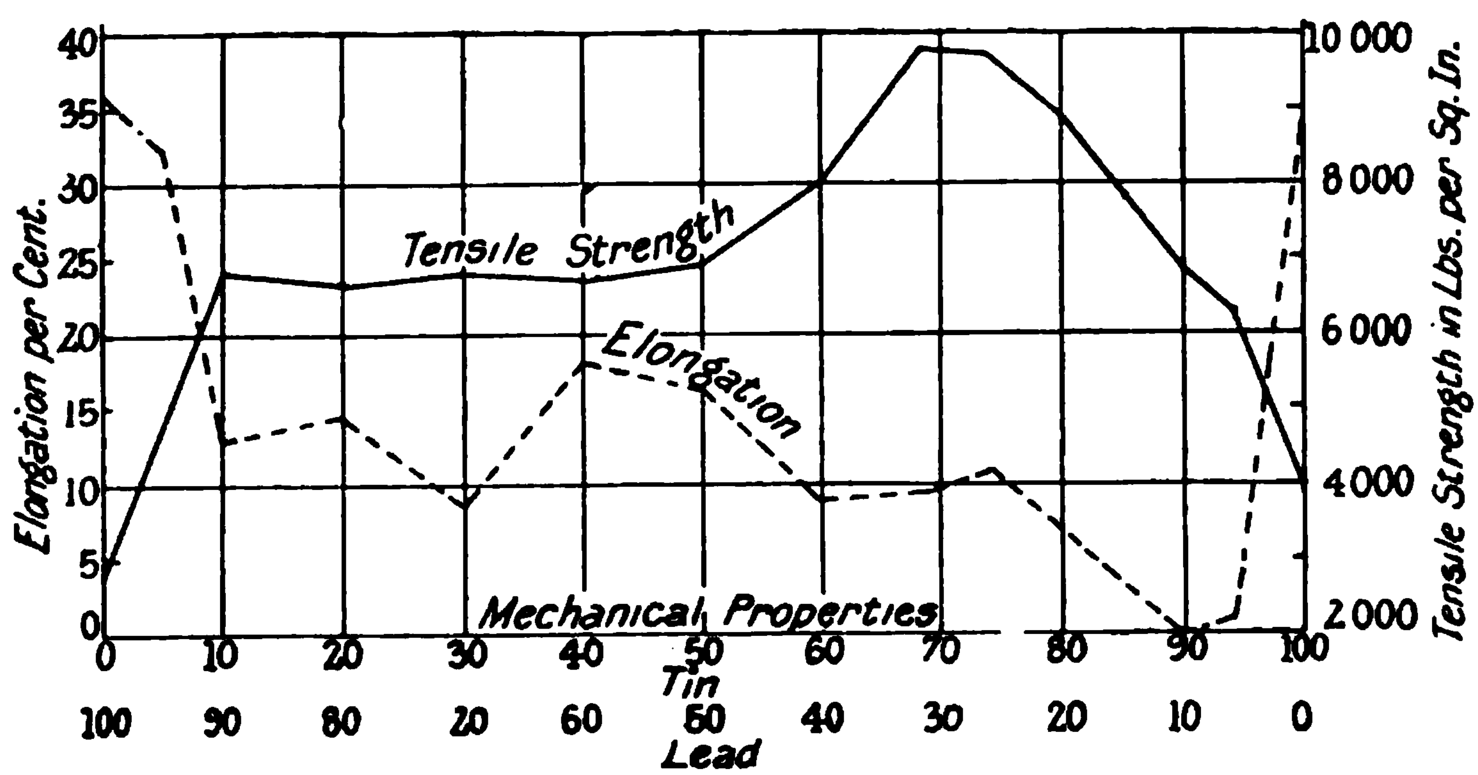



Fig. 46.—Strength Properties of Lead-Tin Alloys.

be observed that the addition of tin to lead lowers the melting point of the metal, the eutectic having the lowest melting point consisting of about 68 parts of tin and 32 parts of lead. This eutectic has the highest tensile strength, namely, about 9500 pounds per square inch, with an elongation of about 10 per cent.

In connexion with the bronze-backed bearing shells, the compositions of which are given on p. 103, the following Babbitt liners are recommended—*

TABLE LXIII.

BABBITT-LINING METALS FOR AERO AND AUTOMOBILE ENGINE BEARINGS.

| *No.* | *Percentage composition.* | | | |
|---|---|---|---|---|
| | *Tin.* | *Copper.* | *Antimony.* | *Nickel.* |
| 1 | 90 | 4·5 | 5·5 | — |
| 2 | 89 | 3·5 | 7·5 | — |
| 3 | 89 | 3·0 | 7·0 | 1·0 |
| 4 | 84 | 7·0 | 9·0 | — |
| 5 | 90 | 10·0 | — | — |

Careful soldering is necessary, and in this connexion, "ringing" as a test of good workmanship is not sufficient.

## 3N10—INTERNATIONAL AIRCRAFT STANDARD SPECIFICATIONS FOR BABBITT METAL FOR BRONZE-BACKED BEARINGS.

1. GENERAL.—The general specifications, 1G1, shall form, according to their applicability, a part of these specifications.

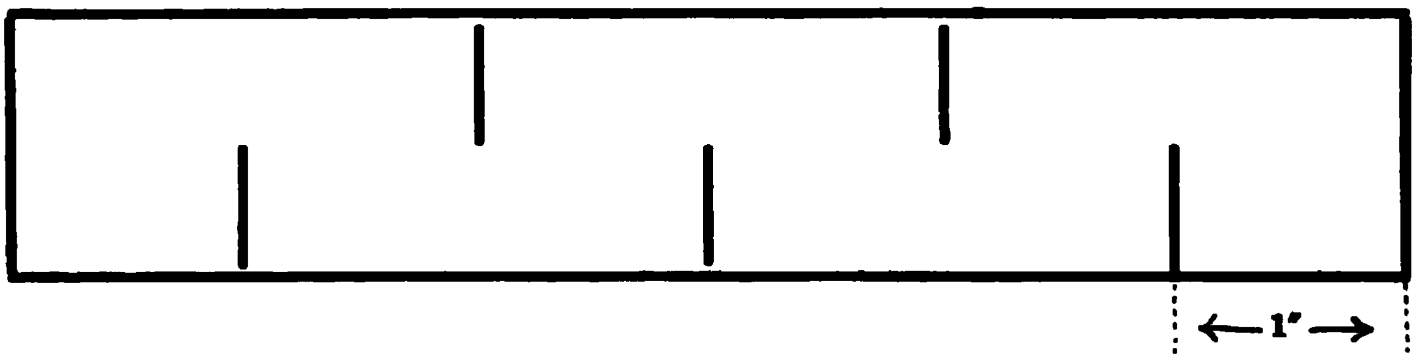
2. MATERIAL.—The composition of the material shall be as follows—

| *Constituent.* | *Desired.* | *Allowable variation.* |
|---|---|---|
| | *Per cent.* | *Per cent.* |
| Tin | 91·00 | 90–92 |
| Antimony | 4·50 | 4–5 |
| Copper | 4·50 | 4–5 |
| Lead, maximum | ·20 | — |

3. SAMPLE FOR ANALYSIS.—(*a*) The inspector shall select one ingot from each lot of 25. The manufacturer shall melt this ingot in a clean ladle and cast therefrom one or more sample bars, 6 inches long, 1 inch wide, and not more than ¼ inch thick.

* C. Peck, The Dochler Die-Casting Co. See *Aviation*, 1st April, 1918.

(*b*) Saw cuts shall be made in each sample bar, as shown in the diagram below. The cuttings shall be thoroughly mixed and must be free from iron and dust. Samples for analysis shall be taken from the mixed cuttings.




4. Manufacture.—(*a*) The Babbitt metal shall be made from lake or electrolytic copper conforming to the I.A.S.B. specification, 2N2, and from the best commercial grades of tin and antimony.

(*b*) No scrap shall be used other than that produced in the manufacturer's own plants and which is of the same composition as the material specified.

### 3N13—Specifications for Soft Solder.

1. General.—The general specifications, 1G1, shall form, according to their applicability, a part of these specifications.

2. Material.—Solder shall be made from new tin and commercially pure new lead. Its composition shall be as follows—

| | *Per cent.* |
|---|---|
| Lead and tin, minimum | 99·8 |
| Tin | 49–51 |
| Antimony, maximum | 10 |
| Zinc | None |

3. Delivery, Shipping, and Packing.—Solder shall be delivered in 1 pound bars. The mark "Half-and-half" shall be cast on each bar. The bars shall be packed in boxes, the gross weight of which shall not exceed 220 pounds (100 kg.).

## Composition of Lead-base Alloys.

Pure lead, although it possesses excellent anti-friction properties is not hard enough for use alone in lining bearings, but by adding antimony, tin, or copper, the lead becomes sufficiently hard to render it suitable for the purpose. Lead-base alloys are in general softer than other anti-friction metals, and are therefore largely employed for slow running or lightly loaded bearings.

Lead and antimony possess the property of being able to combine with each other in all proportions without the anti-friction properties of either being impaired; when about 20 per cent. of antimony is present the resulting alloy is

about the best of the series, and is an excellent one for withstanding high speeds, with a minimum of wear and of heating.

This alloy runs free in the liquid state, and does not shrink appreciably upon cooling ; it is very suitable for lightly loaded high-speed machinery.

The hardness of pure lead is about 4·0 on the Brinell scale, but in the form of a 10 per cent. tin, 90 per cent. lead alloy,

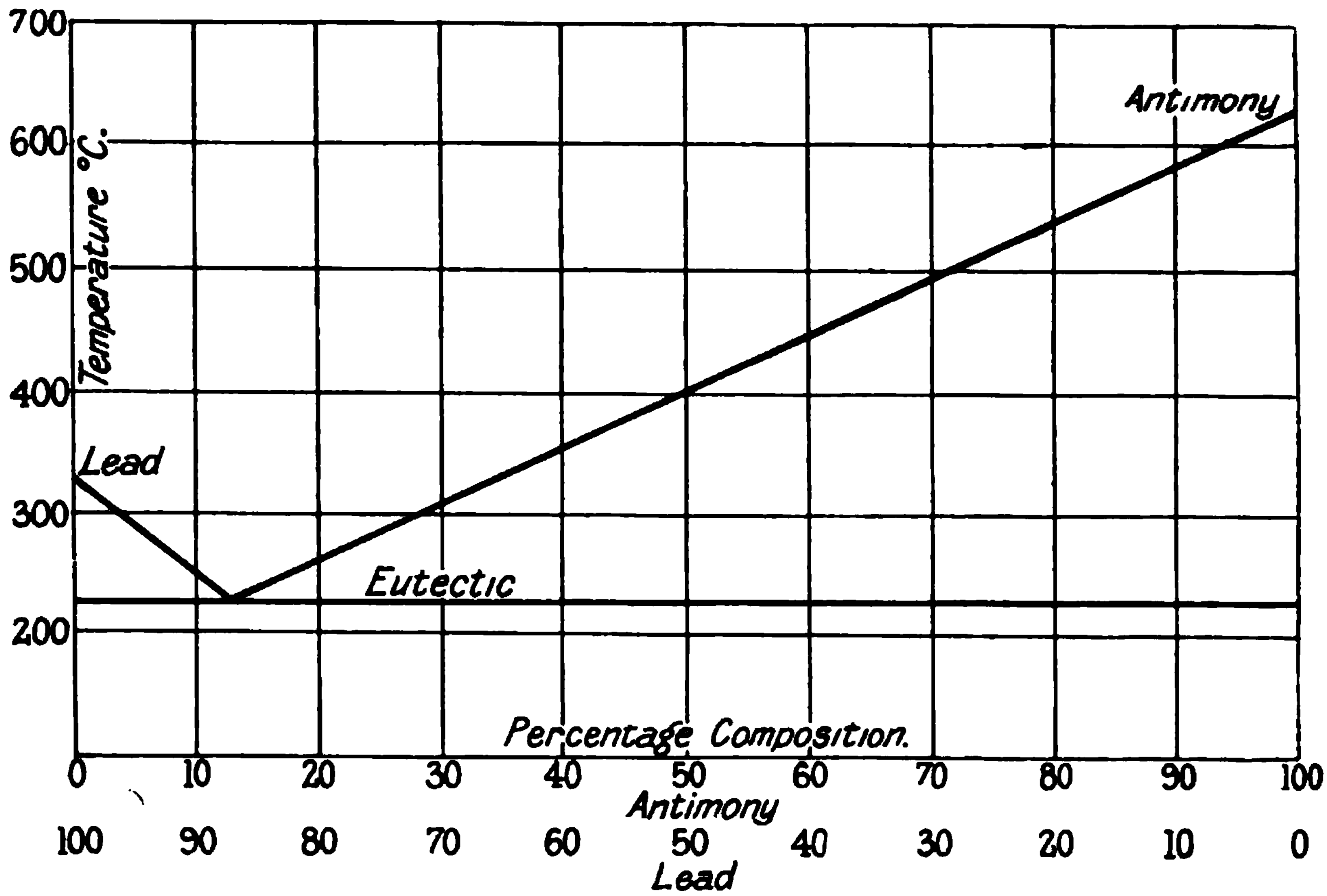



Fig. 47.—The Melting Point Curves for Lead-Antimony Alloys.

it is 10·1, and with 20 per cent. tin, 80 per cent. lead alloy, it is 12·16 ; the maximum hardness of this series is about 16·7 for the 69 per cent. tin, 34 per cent. lead alloy.

Fig. 47 shows the melting points of lead-antimony alloys.

Table LXIV gives the hardnesses of different lead-antimony alloys ; it should be here mentioned that when more than about 18 per cent. of antimony is present the alloy becomes brittle.

## TABLE LXIV.

### Hardness of Lead-Antimony Alloys.

| *Composition, per cent.* | | *Brinell Hardness Number.* 10 *mm. ball.* 100 *kilos. pressure.* |
|---|---|---|
| *Lead.* | *Antimony.* | |
| 98 | 2 | 9 approximate |
| 95 | 5 | 12 „ |
| 90 | 10 | 16 „ |
| 85 | 15 | 17 „ |
| 80 | 20 | 21 „ |

Ternary alloys containing a lead base, but with tin as well as antimony, such as Magnolia metal, graphite bearing metal, and other white-metals, possess good anti-friction qualities and greater hardness than the binary lead-antimony alloys. Ternary alloys of lead with copper and antimony are also in use, a typical composition being as follows: Lead, 80 to 65 per cent.; antimony, 15 to 25 per cent.; copper, 5 to 10 per cent. These alloys are noted for their hardness and durability.

## TABLE LXV.

### Hardness Properties of Lead-Tin-Antimony Alloys.

| *Composition, per cent.* | | | *Brinell Hardness.* | *Remarks* |
|---|---|---|---|---|
| *Lead.* | *Tin.* | *Antimony.* | | |
| 90 | 5 | 5 | 15·2 | |
| 85 | 10 | 5 | 15·1 | |
| 80 | 15 | 5 | 16·7 | |
| 75 | 20 | 5 | 18·0 | |
| 70 | 25 | 5 | 16·8 | |
| 65 | 30 | 5 | 15·1 | |
| 85 | 5 | 10 | 23·2 | Tensile strength a maximum, being over 6 tons per square inch. Ductility a maximum for the series. |
| 80 | 10 | 10 | 25·4 | |
| 75 | 15 | 10 | 26·4 | |
| 70 | 20 | 10 | 23·2 | |
| 65 | 25 | 10 | 24·0 | |
| 80 | 5 | 15 | 25·6 | |
| 75 | 10 | 15 | 31·0 | |
| 70 | 15 | 15 | 32·0 | |
| 65 | 20 | 15 | 27·6 | High tensile strength, but brittle series. Bearings liable to crack in service |
| 75 | 5 | 20 | 26·7 | |
| 70 | 10 | 20 | 37·0 | |
| 65 | 15 | 20 | 35·6 | |
| 70 | 5 | 25 | 27·8 | |
| 65 | 10 | 25 | 33·6 | |
| 65 | 5 | 30 | 28·8 | |

White-metal bearings running in an oil bath are capable of withstanding bearing pressures up to 800 or 900 pounds per sq. in. without seizing, provided that the temperature does not exceed about 160° F., but loads of from 300 to 600 pounds per square inch are the usual ones.

The coefficient of friction for a well-lubricated good quality white-metal bearing varies from about 0·010 for bearing pressures of 100 to 250 pounds per square inch, up to 0·030 for pressures of 700 pounds per square inch and above; the actual coefficient of friction in any particular case will depend upon the nature of the alloy, the lubricant and mode of lubricating, the temperature speed, and bearing pressure. A good average value for normal cases for the coefficient of friction is 0·015.

## TABLE LXVI.

### Compositions of Lead-Base Bearing Metals.

| *Name.* | *Composition per cent.* | | | | | *Remarks.* |
|---|---|---|---|---|---|---|
| | *Lead.* | *Antimony.* | *Tin.* | *Copper.* | *Zinc.* | |
| Babbitt Metal, lead-base, No. 4 .. | 80 | 15 | 5 | — | — | Amer. Soc. for Testing Materials. Standard specns. |
| Ditto. No. 5 .. | 90 | 10 | — | — | — | |
| White-metal .. | 80 | 20 | — | — | — | The best of this binary alloy series Suitable for light high-speed machinery |
| ,, .. | 75–80 | 10 | 5–15 | — | — | Tensile strength over 6 tons per sq. inch; good antifriction qualities |
| Locomotive White-metals, I .. | 70 | 20 | 10 | — | — | Used for eccentric straps, piston rod packings, etc. |
| Ditto. II .. .. | 80 | 8 | 12 | — | — | |
| Graphite Bearing Metal .. .. | 67·75 | 16.73 | 14·37 | — | — | |
| Locomotive Bearing Metal .. .. | 45 | — | 4·5 | 50·5 | — | For passenger and freight car bearings |
| Universal Bearing Metal .. .. | 78 | 16·0 | 6 | — | *Bismuth* 0·25 | |
| American Anti-friction Metal .. | 78·44 | 19·60 | — | *Iron.* 0·65 | 0·98 | |
| Camelia Metal .. | 14·75 | — | 4·25 | 70·20 | 10·20 | |
| Ajax Metal .. | 11·5 | — | 11·5 | 77·0 | — | |

## TABLE LXVII.

MISCELLANEOUS LEAD, TIN, AND ZINC ALLOYS.

| *Name.* | *Lead.* | *Tin.* | *Zinc.* | *Other constituents.* | *Remarks.* |
|---|---|---|---|---|---|
| Britannia Metal | — | 90·62 | — | Antimony, 7·81; Copper 1·46 | Birmingham sheet |
| Ashberry Metal | — | 77·8 | 2·8 | Antimony, 19·4 | |
| Pewter .. .. | 20 | 80 | — | — | |
| Type Metal .. | 70 | — | — | Copper, 2·0; Antimony, 18·0 | |
| Shot Metal .. | 99·6 | — | — | Arsenic, 0·2–0·4 | |
| Stereotype Metal | 82·0 | 3·2 | — | Antimony, 14·8 | For stereotyping |
| Plate Pewter .. | — | 89·3 | — | Copper, 1·8; Antimony, 7·1 | |
| Fine Solder .. | 33·3 | 66·6 | — | — | The melting point increases with the lead content |
| Tin Solder .. | 50·0 | 50·0 | — | — | |
| Plumber's Solder | 66·6 | 33·3 | — | — | Authorized by the Plumbers' Company. |
| Expanding Alloy | 75 | — | - - | Antimony, 16·7; Bismuth, 8·3 | This metal expands upon cooling |

## DELTA WHITE ANTI-FRICTION METALS

Delta metals, Nos. IX and XI, are well-known white-metals which are used for lining bearings and bushes, the former being adaptable for general work and the latter for the bearings of heavy machinery such as heavy petrol, oil, and gas engines, locomotives, high speed steam engines, and marine work. It is stated by the manufacturers that these metals are suitable for bearings exposed to grit and dust, as in the case of foundries, collieries, and cement works.

The melting point of the metals is about 237° C. (450° F.), and care should be taken not to over-heat the metal; a reducing flame muffle, or furnace similar to that shown in Fig. 48* is recommended for the purpose.

Bearings to be lined should be carefully cleaned and tinned with a stick of the same metal.

The results given in Table LXVIII refer to tests made upon the IX grade metal by Prof. W. C. Unwin. It will be observed that the bearing pressures employed range from about 128 up to 513 pounds per square inch, and that the maximum "mean" temperature value did not exceed 86·4° F.

* Manufactured by The Monometer Co.

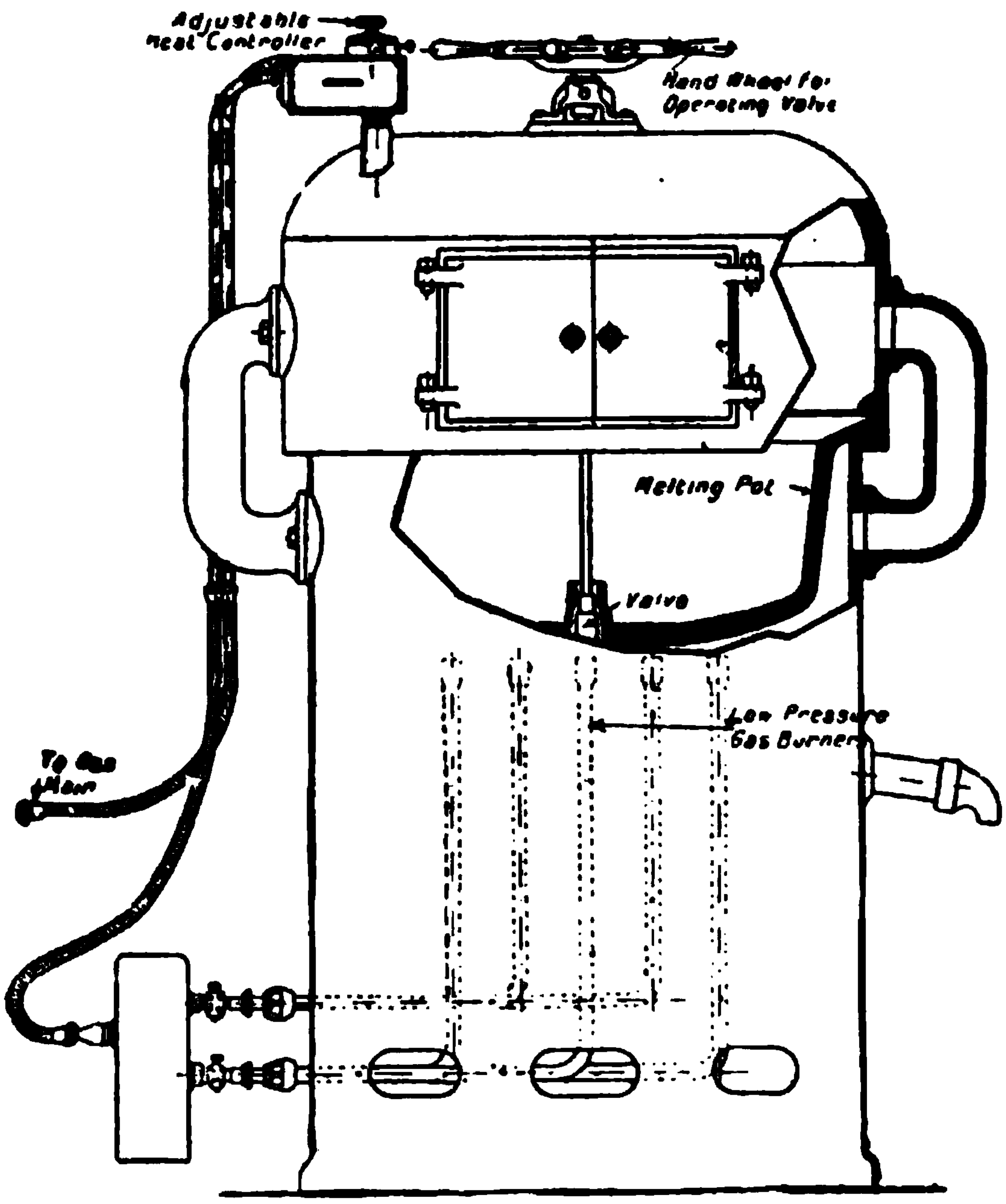



FIG. 48.—BEARING METAL MELTING FURNACE.

## TABLE LXVIII.

### FRICTION TEST RESULTS FOR DELTA No. IX METAL. (Unwin.)

| *Mean revs. per minute* | *Mean pressure per sq. inch-pounds.* | *Mean Temp. ° Fah.* | *Mean Moment of Friction, pounds-inches* | *Net pressure on one step in pounds.* | *Friction on one step at formal surface inch-pounds.* | *Coefficient of Friction.* |
|---|---|---|---|---|---|---|
| 123 | 128·35 | 62·65 | 9·25 | 477·5 | 6·17 | 0·01202 |
| 123 | 256·70 | 64·00 | 16·26 | 955 | 10·84 | ·01135 |
| 123 | 385·05 | 65·75 | 24·23 | 1432·5 | 16·15 | ·01128 |
| 125 | 513·40 | 67·70 | 40·87 | 1910 | 27·25 | ·01428 |
| 315 | 128·35 | 73·80 | 12·00 | 477·5 | 8·00 | ·01675 |
| 315 | 256·70 | 76·20 | 17·25 | 955 | 11·5) | ·01204 |
| 315 | 385·05 | 80·05 | 26·00 | 1432·5 | 17·33 | ·01210 |
| 315 | 513·40 | 86·40 | 44·63 | 1910 | 29·75 | ·01558 |

It will be seen that the friction shows a general increase with speed and pressure.

## HOYT METALS*

A number of anti-friction metals, including I.C.E. (Internal Combustion Engine), No. 11, Plastic, Arrow, Star, and other metals are included under the above general name; each of these alloys is intended for a specific purpose or range. The two former metals are probably the most widely employed in automobile, aeroplane, and general internal combustion engine work.

The I.C.E. grade of white-metal is a copper-hardened tin-base alloy, and is recommended for internal combustion engines, high-speed steam engines, turbines, pumps, wood-working plant, marine engine, and propeller shaft bearings, etc.

It is capable of withstanding high bearing pressures and speeds, and effectively resists the action of salt water.

The No. 11 alloy is stated to be the most durable and satisfactory of the white-metals; it has been very widely employed for aeroplane and car engine lined-bearings.

This alloy, which has a high tin content, with the addition of suitable hardening materials, is very tough, elastic, and hard; it has a compressive strength of about 20 tons per square inch (at this pressure cracks begin to occur).

The Brinell hardness value is 21 to 24 when run in the ordinary manner, and from 24 to 26 when die-cast.

The specific gravity is 7·34, the weight per cubic inch being 0·263 pounds; owing to its low specific gravity as compared with lead-base metals (from 9 to 11) the same weight of metal will occupy a larger volume than the latter metals.

This alloy becomes sufficiently fluid for casting into the bearing shell at 316° C. (or about 600° F.) and it is essential not to over-heat the metal.

This white-metal is suitable for lining connecting rod big-ends, steel and bronze bearings, crank-shaft bearings, and cam-shaft bearings; it is usually supplied in the die-cast form for aeroplane engine bearings, the metal being cast under pressure in metal moulds, true to size, so that no

* Manufactured by the Hoyt Metal Co., Putney, London.

machining is necessary. The process of die-casting improves the hardness, strength, and wearing qualities of the metal.

Fig. 49 illustrates the plasticity and toughness of the No. 11 alloy, the specimen shown having been twisted and hammered cold.

FIG. 49.

FIG. 50.—ILLUSTRATING METHOD OF LINING BEARINGS.

## METHOD OF LINING BEARINGS

The bearing shell is supported either in a horizontal or vertical position, and a jig *A* (Fig. 50) is provided so that bearings of the same size can be quickly accommodated. A central mandrel *D* is provided (which should be hollow and as thin as possible), fixed to the jig, and its diameter should

be chosen so that there is a minimum of metal for machining left, after pouring; if the white-metal employed has an exceedingly small contraction or shrinkage the mandrel should be only a few thousandths of an inch smaller in diameter than the bearing shaft itself.

In cases where the bearing is turned to size after being lined, instead of being scraped in, the usual machining allowance should be given, the size of the mandrel being chosen accordingly.

If the bearings to be lined have the oil-holes or orifices machined in them, these should be plugged up with clay or with an asbestos pad or plug, held in place by means of iron wire; asbestos and water or oil kneaded together to form a thick paste is also frequently employed. The mandrel itself should be coated with graphite or lamp-black before inserting in the jig, in order to prevent sticking.

The bearing shells should be previously thoroughly cleaned, heated in a non-oxidizing flame (a clean Bunsen flame being very suitable for the purpose), and tinned with a strip of the same metal as that of the white-metal lining (in the case of tin-base and similar alloys), using "killed spirits" or sal-ammoniac as a flux. The coated shell should be thoroughly coated and wiped; when cool it is placed in position in the jig, ready for pouring.

It is essential, after tinning, to remove all traces of the flux by wiping with tow, or hemp sacking, and washing in hot water.

The white-metal should be kept melted at the lowest temperature* appropriate for the particular alloy used. For Hoyts' I.C.E., or No. 11 alloy, a temperature of about 310° C. (or 600° F.) is about correct. In the absence of a thermometer, a rough method of judging the correct temperature is to dip a piece of ordinary white writing paper into the metal; if the metal is at the correct temperature the paper enters freely and turns light brown, but if too hot it catches fire.

* The melting points of low fusion alloys are given on p. 151.

The metal should be heated in a suitable muffle or pot,* provided with means for regulating the heat supply, and for stirring the molten metal.

The metal should on no account be over-heated, as it loses its good anti-friction and strength qualities.

If the metal is kept molten for any length of time it should be covered with a thin layer of vegetable charcoal. The jig, bearing shell, and mandrel should be heated with a blow-lamp or suitable reducing flame until the tinned surface of the shell just begins to run; this is the correct temperature at which to pour the molten metal into the space between the mandrel and bearing shell.

Immediately the bearing has been filled the blow-lamp should be turned on to the top of the metal to keep it just molten until it is seen to sink a little, when more molten metal is poured in, until it is on the point of flowing over. After this the bearing may be cooled quickly with a cold air blast or wet sponge or cloth, starting at the lowest side, or end, of the bearing first.

In some cases a casting "head" and suitable vents are arranged so that there is a pressure upon the metal in the mould itself; this ensures cleaner castings, and the shrinkage can be made to occur in the feeder or runner itself.

## DIE AND CHILL BEARINGS

As previously mentioned, the anti-frictional and strength qualities of a bearing metal are appreciably improved by die or chill casting, the texture of the metal being rendered more uniform and finer in constitution.

Other advantages of die-casting are that the bearings can be cast true to size (the degree of accuracy being about $\frac{1}{1000}$ of an inch), so that no subsequent machining is required, and that they can be turned out in large numbers rapidly.

Special die casting machines are now used for this purpose; a typical example is shown in Fig. 9, p. 24.

* A suitable melting furnace is shown on p. 158.

When bearings are chill-cast, as by the Eatonia* process, a marked improvement in the wearing qualities is obtained. An example of this improvement may be mentioned in the case of two white-metal bearings, each 6 inches long by 3 inches diameter, cast from the same mixture. One of the bearings was poured in the ordinary way, and the other was cast by the Eatonia process in a water-cooled mould. The bearings were run in an oil-bath. For the first hour the pressure on each was 60 pounds per square inch, the speed being 600 R.P.M.; the pressure was then increased to 1000 pounds per square inch. After 40 minutes running, the ordinary bearing seized up, the oil-bath temperature being 137·5° F., whereas the other bearing was still running when the load was removed after 2 hours, and after a further 2 hours running with a load of 60 pounds per square inch. The maximum temperature attained in this case was 149° F., at the end of the 2 hours under the 1000 pounds per square inch load; the initial temperature of the oil-bath was 60° F. in each case. The coefficient of friction in the latter case was 0·0034. The density of the metal is increased by die or chill casting.

* See p 113.

## CHAPTER IV

# NICKEL AND ITS ALLOYS

NICKEL is a hard, silver-white metal having a specific gravity of 8·8 and a melting point of 1427° C. It does not readily tarnish in air, and is capable of taking a high polish. Commercial nickel contains small quantities of impurities such as carbon (up to 0·20 per cent.), copper (up to 0·20 per cent.), arsenic (up to 0·025 per cent.), cobalt (up to 1·0 per cent.), iron (up to 0·75 per cent.), silicon (up to 0·30 per cent.), and sulphur in very small amounts.

Carbon, when present in the combined form, tends to strengthen nickel, but in the graphitic state renders it brittle.

Iron, cobalt, and chromium tend to harden and strengthen nickel. Nickel readily occludes carbon-monoxide and other gases and possesses a strong affinity for carbon, and is therefore difficult to obtain in the pure state, when cast; the effect of the presence of carbon is to appreciably lower the melting point of nickel.

Nickel has a specific heat of 0·108, and a coefficient of linear expansion of 0·0000127 per degree C.; its thermal conductivity in C.G.S. units is 0·141 and its resistivity is $11{\cdot}8 \times 10^6$ at 18° C.

The resistance of nickel is higher than that of most other common metals, as the following table shows, and for this reason nickel and some of its alloys, such as *constantan* and *manganin*, are used for electrical resistances, electrical heating apparatus, and in electrical instruments.

Nickel is magnetic, like iron.

Nickel is fairly ductile, lying between iron and copper in the order of ductility, and it can be rolled and drawn into fine wire.

## TABLE LXIX.

### SPECIFIC RESISTANCE OF METALS.

(Sir Roberts Austen.)

| *Metal.* | *Resistance of a rod 1 centimetre long by 1 square centimetre cross-section at 0° C. in Ohms × $10^6$.* |
|---|---|
| Silver .. .. | 1·50 |
| Copper .. .. | 1·57 |
| Gold .. .. | 2·24 |
| Aluminium .. | 2·62 |
| Magnesium .. | 4·31 |
| Iron .. .. | 10·68 |
| Platinum .. .. | 11·19 |
| Nickel .. .. | 12·00 |
| Lead .. .. | 19·80 |

The following are the mechanical strength properties of nickel in the dead soft wrought state—

| | |
|---|---|
| Elastic limit .. .. .. | 6–10 tons per square inch |
| Tensile strength .. .. | 18–20 ,, ,, ,, |
| Elongation .. .. .. | 8–15 per cent. |

The tensile strength and elongation of nickel in different conditions is given in the following table—

## TABLE LXX.

### PROPERTIES OF NICKEL. (Kent.)

| *Condition.* | *Tensile strength, Tons per square inch.* | *Elongation, per cent.* |
|---|---|---|
| Castings .. .. .. | 38 | 12 |
| Wrought .. .. .. | 43 | 14 |
| Wrought (annealed) .. | 42·4 | 23 |
| Hand rolled .. .. | 34·8 | 10 |

It has been shown* that a small quantity of pure magnesium will free nickel from occluded gases, and that it gives a metal capable of being drawn or rolled, perfectly free from blow-holes, to such an extent that the metal may be rolled into thin sheets in widths up to 3 feet.

Aluminium or manganese are also equally good as purifying agents, but they harden the metal.

The effect of low temperature upon the properties of nickel

* "Metallurgy," p. 25. Sir Roberts Austen.

is somewhat remarkable, the tensile strength at the temperature of liquid air (– 90° C.) being 46 tons per square inch, the ductility 51 per cent., and the hardness from 100 at normal temperatures to 150 in liquid air.

It is also known that the presence of nickel in iron alloys, such as nickel-steel and iron-nickel-manganese, prevents these alloys from being injured by low temperatures such as – 150° C. to – 200° C.

Nickel is a valuable constituent in many of the more important commercial alloys such as nickel-steel, nickel-chrome steel, German-silver, monel-metal, nickel-silver, platinoid, manganin, constantan, and coin metals.

Nickel is also used for coating metal surfaces, such as iron, steel, and copper alloys, for decorative and protection purposes, the electro-plating process being a typical one.

The following table gives the compositions of some of the better known alloys of nickel with copper, tin, and iron.

## TABLE LXXI.

### THE COMPOSITION OF NICKEL ALLOYS.

| *Name.* | *Copper.* | *Nickel.* | *Zinc.* | *Tin.* | *Iron.* | *Cobalt.* |
|---|---|---|---|---|---|---|
| German silver .. .. | 50–52 | 14–26 | 0–32 | 3–23 | — | — |
| 18 per cent. German silver .. | 58 | 18 | 24 | — | — | — |
| German Silver (Perrine)— | | | | | | |
| Grade 1 .. .. .. | 57 | 12·5 | 30·5 | — | — | — |
| Grade 2 .. .. .. | 56 | 20 | 24 | — | — | — |
| Grade 3 .. .. .. | 50 | 30 | 20 | — | — | — |
| Nickel silver .. .. .. | 75–65 | 25–35 | — | — | — | — |
| Nickel silver* (Thompson) .. | 46 | 39 | 20 | — | — | — |
| Sheffield table-ware .. | 45·7–60 | 31·6–15 | 25·4–17 | — | 0–2·6 | 0–3·4 |
| Austrian ,, .. .. | 50–60 | 25–30 | 25–20 | — | — | — |
| French ,, .. .. | 50 | 19–20 | 30–32 | — | — | — |
| Amer. nickel-copper castings | 52·5 | 17·7 | 28·8 | — | — | — |
| ,, ,, bearings | 50 | 25 | 25 | — | — | — |
| ,, ,, 1 cent coin | 88 | 12 | — | — | — | — |
| Nickel coins .. .. .. | 75 | 25 | — | — | — | — |
| Nickel bullet casings .. .. | 80 | 20 | — | — | — | — |
| Chinese packfong .. .. | 40·4† | 31·6† | 6·5† | — | — | — |
| ,, tutenag .. .. | 8† | 3† | 6·5† | — | — | — |
| Constantan .. .. .. | 60 | 40 | — | — | — | — |
| Monel metal .. .. | 26·5 | 72 | — | — | 1·5 | — |
| | | | | | *Ferro-Manganese* | |
| Manganin .. .. .. | 65 | 5 | — | — | 30 | — |

* This grade is recommended as possessing the best all-round properties. "The Annealing of Nickel Silver," Thompson. *Journ. Inst. of Metals*, March, 1916.

† Parts, not percentages.

TABLE LXXII.

ELECTRICAL PROPERTIES OF NON-FERROUS MATERIALS FOR RESISTOR WIRES, ETC.

| *Material.* | *Composition.* | *Resistivity at 20° C.* | *Coeff. of Resist. Increase with Temp. at 20° C. per degree C.* | *Specific Gravity.* | *Tensile Strength. Lbs. per sq. in.* | *Melting Point. ° C.* |
|---|---|---|---|---|---|---|
| *Aluminium.* | | *Microhms per cm.* | | | | |
| Copper .. | Annealed | 1·724 | ·00393 | 8·89 | 34,000 | 1083 |
| Nickel .. | — | 11·8 | 0·004 | 8·9 | 160,000 | — |
| Nickeline I.. | — | 43.6 | 0·000076 | 8·4 | — | — |
| „ II.. | — | 33·9 | 0·000168 | 8·4 | — | — |
| Manganin .. | Cu-Mn-Ni | 41 to 74 | 0·000039 | — | — | — |
| Monel Metal | Cu-Ni | 42·6 | 0·00198 | 8·9 | 160,000 | — |
| German Silver | Cu-Ni (30%)-Zn | 48·2 | 0·00020 | 8·5 | — | 1160 |
| „ „ | Cu-Ni (18%)-Zn | 33·3 | 0·00031 | 8·5 | 150,000 | 1027 |
| Constantan.. | Cu-Ni | 50·0 | 0·000005 | 9·73 | — | — |
| Nichrome I | Ni-Cr. | 99·6 | 0·00044 | 8·15 | 150,000 | 1540 |
| „ II | Ni-Cr. | 109·5 | 0·00016 | 8·02 | 150,000 | 1565 |
| Ferro-Nickel | Fe-Ni | 28·2 | 0·00207 | 7·8 | 175,000 | — |
| Tarnac .. | Cu-Mn-Ni | 42·0 | 0·000025 | — | — | — |
| Therlo .. | Cu-Mn-Al | 46·7 | 0·000006 | 8·15 | — | — |

## GERMAN SILVER

German silver is an alloy of copper, nickel, and zinc, and is a hard, silvery-white metal which is capable of taking and retaining a high polish ; it is practically incorrodible. The proportions of the constituents of German silver vary considerably, the cheaper alloys containing low percentages of nickel (10 to 15 per cent.), whilst the best varieties contain from 18 to 25 per cent. of nickel, from 20 to 30 per cent. of zinc, and the remainder copper.

German silver is a difficult metal to handle in the foundry or rolling mill, but it can be produced in the form of rods, sheets, or wire.

It is chiefly used for electrical purposes, on account of its high resistance, for resistance and heating coils. The resistance of ordinary German silver is about 20 times that of copper, and it increases with the nickel content as the following results show.

## TABLE LXXIII.

### Resistances of German Silver.*

| *Composition.* | | | *Resistance in terms of that of Copper.* | *Relative Resistances.* |
|---|---|---|---|---|
| *Copper.* | *Nickel.* | *Zinc.* | | |
| 57 | 12·5 | 30·5 | 11 | 1·0 |
| 56 | 20 | 24 | 14–18 | 1·25–1·65 |
| 50 | 30 | 20 | 28 | 2·51 |

The specific gravity of 18 per cent. German silver is about 8·5, and its tensile strength from 16 to 19 tons per square inch, with from 33 to 30 per cent. elongation.

Its coefficient of resistance increase with temperature is low, being ·00044 per ° C. at 18° C., that of copper being ·00428. The resistivity of German silver of the following composition, namely 62 copper, 15 nickel, and 22 tin varies from ·000016 to ·000040, at 20° C., the mean value at 0° and at 100° C. being given by Lorenz as ·000027. The following† are the values of the resistances per metre for copper and German silver.

| S.W.G. .. | 12 | 14 | 16 | 18 | 20 | 22 | 26 | 30 | 34 | 38 | 42 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Resistance in Ohms/metre.* | | | | | | | | | | | |
| (1) Copper | ·0032 | ·0054 | ·0083 | ·0148 | ·0260 | ·0435 | ·105 | ·222 | ·404 | ·950 | 2·1 |
| (2) German Silver | ·041 | ·070 | ·109 | ·193 | ·345 | ·570 | 1·38 | 2·90 | 5·27 | 12·4 | 27·8 |

The melting point of this metal is about 1027° C., the maximum working temperature being 260° C.

The coefficient of linear expansion is 0·0000173 per ° C. 30 per cent. German silver has a specific gravity of 8·5; its melting point is about 1160° C.

The following table‡ gives the principal mechanical properties of German and nickel silvers.

* Ordinary 18 per cent. German silver has about 18 times the resistance of pure copper.

† Kaye and Laly.

‡ "The Annealing of Nickel Silver," Thompson, *Journ. of Inst. of Metals*, Mar., 1916.

## TABLE LXXIV.

### The Composition and Properties of Nickel Alloys.

| *Composition.* | | | *Manganese added.* | *Yield Point, tons per sq. inch.* | *Tensile strength, tons per sq. inch.* | *Elongation, per cent. in 2 inches.* | *Reduction of area, per cent.* |
|---|---|---|---|---|---|---|---|
| *Copper.* | *Zinc.* | *Nickel.* | | | | | |
| 60·6 | 31·7 | 7·6 | — | 7·16 | 16·88 | 34·5 | 37·2 |
| 60·2 | 31·8 | 7·8 | 0·25 | 6·60 | 15·28 | 46·5 | 46·9 |
| 61·8 | 21·7 | 16·4 | — | 9·00 | 17·80 | 39·5 | 32·7 |
| 61·2 | 23·2 | 15·5 | 0·25 | 8·12 | 18·36 | 39·0 | 45·9 |
| 61·6 | 15·9 | 22·4 | — | 8·52 | 17·20 | 24·5 | 26·7 |
| 61·6 | 18·5 | 19·8 | 0·25 | 8·24 | 19·36 | 32·5 | 33·5 |
| 55·7 | 26·7 | 17·4 | — | 9·04 | 17·12 | 33·5 | 37·8 |
| 54·3 | 29·7 | 15·8 | 0·25 | 8·92 | 16·88 | 38·5 | 40·0 |
| 56·2 | 27·6 | 16·3 | 1·50 | 9·04 | 17·96 | 44·0 | 41·1 |
| 61·2 | 9·8 | 28·6 | — | 8·76 | 19·72 | 32·0 | 36·7 |
| 60·4 | 11·4 | 27·9 | 0·25 | 10·32 | 23·68 | 29·0 | 29·7 |
| 60·9 | 13·2 | 26·7 | 1·50 | 10·88 | 24·16 | 35·0 | 33·1 |

## NICKEL SILVER

This is an alloy of copper, nickel, and zinc, containing from 25 to 35 per cent. of nickel, 0 to 25 per cent. of zinc, and the balance of copper ; the more expensive nickel-silvers contain the higher percentages of nickel, with little or no zinc.

The compositions of nickel-silvers for table-ware are given in Table 71.

The principal applications of nickel-silver are for ornamental forks, spoons, knives, and other table-ware parts. The cheaper grades of so-called silver-ware consist of silver plated nickel-silver goods.

## MONEL METAL*

This is a high nickel-copper alloy consisting of approximately 68 to 70 per cent. of nickel, 26 to 28 per cent. of copper, and 3 to 5 per cent. of other metals, including from 1 to 2 per cent. of iron. It contains no tin, zinc, or antimony.

* Manufactured in England by Messrs. G. & J. Weir & Co., Ltd., Glasgow.

In appearance it cannot be distinguished from pure nickel, and it gives the same finished effect. It is strong, ductile, and tough, being greatly superior to copper and bronze under corroding influences.

Cast monel metal has a minimum tensile strength of about 25 tons per square inch, whilst in the rolled state the tensile strength varies from about 34 to 44 tons per square inch.

The metal can be forged, soldered, brazed, and electrically welded.

The following are the physical properties of monel metal—

| | |
|---|---|
| Melting point .. .. .. .. | 1360° C. (2488° F.) |
| Specific gravity (cast) .. .. | 8·87 |
| Weight per cubic inch (cast).. .. | 0·319 lbs. |
| Weight per cubic inch (rolled) .. | 0·323 lbs. |
| Coefficient of expansion (20° C.–100° C) | 0·00001375 per 1° C. |
| Electrical resistivity .. .. .. | 256 ohms per mil-foot |
| (Temp. coefficient) .. .. .. | 0·0011 per 1° F. |
| Electrical conductivity .. .. | 4 per cent. (copper 100 per cent.) |
| Heat conductivity .. .. .. | $\frac{1}{18}$ that of copper |
| Shrinkage .. .. .. .. | $\frac{1}{4}$ inch per foot |
| Hardness cast material .. .. | 20–23 (shore scleroscope) |
| Hardness hot-rolled rods .. .. | 27 (average shore scleroscope) |
| Modulus of elasticity .. .. | 22,000,000–23,000,000 |
| Torsional tests on rods (average)— | |
| Shearing stress —Lbs. per square inch on remotest fibres— | |
| At elastic limit .. .. .. | 31·796 |
| At ultimate load.. .. .. | 79,053 |
| Compression tests on rods— | |
| Elastic limit .. .. .. | 25,500–32,000 pounds per sq. in. |
| Compression tests on castings— | |
| Elastic limit .. .. .. | 12,000–25,500 pounds per sq.in. |
| Tensile tests on castings— | |
| Yield point .. .. .. .. | 32,000 pounds per sq. inch |
| Tensile strength .. .. .. | 60,000 pounds per sq. inch |
| Elongation in 2 inches .. .. | 20 per cent. |
| Tensile tests on rods (average of last 100 tests made in 1913)— | |
| Yield point .. .. .. .. | 55,587 pounds per sq. inch |
| Tensile strength .. .. .. | 88,232 pounds per square inch |
| Elongation in 2 inches .. .. | 42 per cent. |

## Forms of Monel Metal.

Monel metal can be obtained commercially in the following forms: (*a*) Castings, (*b*) forgings, (*c*) hot-rolled rods and bars, (*d*) wire, (*e*) bolts, nuts, and washers, (*f*) wire cloth, (*g*) boat fittings, (*h*) pump rods and liners, (*j*) aeroplane cables and parts, (*k*) burning and enamelling points,* etc.

* For holding articles, such as cooking utensils, in enamelling and japanning ovens, and in corrosive gases.

**Monel Metal Forgings.**

Monel metal can be forged on heating it to a temperature of 950° to 1100° C. (1380° to 1740° F.). It is preferable to heat the metal in a muffle furnace, but good results may also be obtained by heating it in a gas or oil-fired furnace, using either a neutral or a slightly oxidizing flame, free from sulphur. The piece to be forged should be turned over frequently while in the furnace, to avoid local heating. It should not be forged below 900° C.

Owing to the fact that this metal loses its heat quickly upon its removal from the furnace, there should be the minimum loss of time in handling from the furnace.

Monel metal forgings closely resemble steel forgings in their properties, and in addition are non-corrodible. This metal is very suitable for steam and water valves, pump fittings, etc., and whilst being more non-corrosive than 25 per cent. nickel steel, possesses much better mechanical strength properties.

**Non-Corrosive Properties of Monel Metal.**

Reference has already been made to the high resistance to corrosive influences of this alloy, combined with a high degree of strength.

Monel metal is now used for marine purposes, and offers a great resistance to the action of sea-water ; it is suitable for condenser fittings, under water parts, marine propellers, pump fittings, such as pump rods, valves, and liners, etc.

In sheet and tin-plate mills, it is used for pickle frames and rods, and is stated to be superior to the best bronzes in strength and resistance to corrosion.

Monel metal is also employed in binding tanks and vats for platers, tanners, bleachers, chemical works, etc.

**Annealing Monel Metal.**

For annealing the metal should be heated to a temperature varying from 700° to 950° C., according to the degree of

softness desired in the finished product. When annealing monel metal which is to be used for cold drawing of wire, or blading, the higher temperature of 950° C. should be used.

The temperature should be maintained for at least 1 hour, but the rate of cooling is not important, as this alloy has no critical points.

The colour indications of temperature are as follows—

| | |
|---|---|
| 900° C. .. .. .. | Red |
| 1040° C. .. .. | Salmon colour |
| 1100° C. .. .. | Orange |

### Pickling Monel Metal.

For pickling this metal, in order to remove scale formed under heat treatment, a solution of hydrochloric acid made up of 1 part commercial acid to 3 parts water is suitable. To this solution an excess of finely powdered oxide of iron should be added, and this excess should be maintained throughout. For the best results a temperature of about 70° C. for the pickling bath is necessary.

### Strength Properties of Monel Metal.

The following table gives some results of tests made upon different forms of this alloy—

TABLE LXXV.

STRENGTH PROPERTIES OF MONEL METAL.

| *Condition.* | *Elastic limit, tons per sq. inch.* | *Tensile strength, tons per sq. inch.* | *Elongation per cent. on 2 inches.* | *Reduction of area, per cent.* |
|---|---|---|---|---|
| Bar from 1 inch square casting .. .. | 14·2 | 35·5 | 49·2 | 39·3 |
| Hot-rolled 1 inch rod | 25·9 | 39·4 | 36·0 | 67·9 |
| Wire* .. .. | — | 40 | — | — |
| Rolled sheets .. | — | 35–45 | — | — |
| Ordinary castings .. | — | 30–36 | — | — |

* Composition of wire: Nickel, 68 per cent.; copper, 28 per cent.; iron, 9·5 per cent.; and manganese, 1·5 per cent.

The influence of temperature upon the strength of monel metal is shown by the following test results—*

## (A) TENSILE TEST RESULTS.

### ROLLED MONEL METAL.

| *Temperature, ° Fah.* | *Tensile strength, tons per sq. inch.* | *Elastic limit, tons per sq. inch.* | *Elongation in 2 inches per cent.* | *Reduction of area, per cent.* |
|---|---|---|---|---|
| 70 | 46·8 | 34·9 | 31·3 | 61·7 |
| 300 | 44·4 | 26·1 | 29·7 | 57·8 |
| 450 | 44·6 | 26·2 | 29·7 | 51·0 |
| 525 | 43·0 | 26·1 | 32·8 | 59·5 |
| 600 | 39·9 | 25·9 | 32·8 | 59·5 |
| 750 | 30·8 | 19·0 | 28·1 | 58·1 |
| 1030 | 21·0 | 11·9 | 28·1 | 60·7 |

## (B) TORSION TEST RESULTS.

### $1\frac{1}{8}$ INCH ROLLED MONEL METAL.

| *Temperature, ° Fah.* | *Torsional strength, tons per sq. inch.* | *Elastic limit, tons per sq. inch.* | *Number of twists.* |
|---|---|---|---|
| 70 | 41·0 | 16·8 | 11 and 150° |
| 385 | 34·8 | 16·1 | 4 and 340° |
| 600 | 25·3 | 10·3 | 4 and 215° |
| 800 | 17·3 | 4·5 | 7 and 50° |

## PLATINOID

This metal is an alloy resembling German silver, but with the addition of from 1 to 2 per cent. of tungsten, which is introduced in the form of phosphor-tungsten, the phosphorus being removed in the dross formed.

Platinoid is a white metal resembling silver, and is capable of taking and retaining a high polish.

Its resistivity is about $1\frac{1}{2}$ times that of German silver, and it closely resembles this alloy in its electrical properties; it has a remarkably low coefficient of resistance increase with temperature.

* From *The Valve World.*

## NICKEL-COPPER ALLOYS

Nickel in its affinities and properties resembles both iron and copper. Like iron it forms a series of alloys with carbon, giving the complete range from those similar in carbon content to the very mildest steels up to those similar to cast iron. This carbon, while having an important bearing on the properties of the metal, does not have the very great influence that carbon has on all classes of iron and steel, since nickel does not form with carbon the series of molecular rearrangements and changes in the solid which impart the varying qualities to annealed, hardened, and tempered steel.

It has, further, a magnetic transformation point exactly similar to that of iron, being magnetic at temperatures below 325° C., and non-magnetic above that point. It has also a high modulus of elasticity, being next to iron in that respect.

All of these properties are carried over to some extent into the nickel-copper alloys. The degree varies with the nickel content, since nickel and copper in alloying form no compounds or eutectics, but simply go into solid solution in each other.

In the alloys of low nickel content these properties are not very well marked, being masked by the large amount of copper present, but when the nickel exceeds about 50 per cent. the alloy changes into a nickel alloy, and with increasing percentages the alloys show more and more clearly the influence of that metal. With about 68 per cent. of nickel, an alloy* is obtained which has a remarkable likeness to iron in some respects, and to bronze in others. From the strength point of view it resembles both, and from the electrical standpoint it resembles the non-ferrous metals.

Copper-nickel alloys may be divided up into three classes, as follows—

(*a*) Those containing up to 5 per cent. of nickel, which are noted for their property of resisting high temperatures without

* See "Monel Metal," p. 169.

undue deterioration; these alloys are used for locomotive fire-box tubes.

(*b*) Alloys containing from 15 to 25 per cent. of nickel, which are noted for their cold-working properties and resistance to deterioration at high temperatures; these alloys are used for fire-box plates, and other similar purposes.

(*c*) Alloys containing from 40 to 45 per cent. of nickel, having high electrical resistivities and low temperature coefficients.

The mechanical properties of the alloy groups (*a*) and (*b*) are given in the following table—

TABLE LXXVI.

PROPERTIES OF COPPER-NICKEL ALLOYS.

| *Name.* | *Condition.* | *Tensile strength, tons per sq. inch* | *Elongation per cent.* |
|---|---|---|---|
| 2 per cent. Nickel, 98 per cent. copper alloy | Hand rolled | 45 | 5 |
| | Hand rolled and annealed at 650° C. | 30 | 45 |
| 20 per cent. nickel, 80 per cent. copper alloy | Hand rolled | 40 | 5 |
| | Hand rolled and annealed | 20 | 35 |

**Constantan.**

This is a copper-nickel alloy containing about 40 per cent. of nickel and 60 per cent. of copper.

It is much used for electrical instruments in the form of resistance wires, and for thermo-couples (with copper as the other element). Its electrical resistance is about 28 to 30 times that of copper, being about 50 microhms-centimetres at 20° C., and it has a very low coefficient of resistance increase with temperature, being 0·000005 per ° C. at 20° C. Its thermo-electric power with copper is 40 micro-volts at 0° C. The density of constantan is 9·73.

Other high resistance nickel alloys are *nickeline* (25 per cent. nickel), and *manganin* (an alloy of copper, nickel, and manganese).

## NICKEL PLATING, Etc.*

The process of nickel-plating consists in giving to the article to be treated a superficial deposit of nickel.

There are two electrolytic methods of depositing metal upon an object, namely—

1. The method in which the article forms the cathode and the metal to be deposited the anode, using a solution of a salt of the anode or a liquid in which the anode is soluble.

2. The method in which the article forms the cathode and the anode is an inert metal, with a suitable electrolyte solution.

In the latter method the solution gradually weakens, so that it is necessary to add new material or solution continuously during the operation in order to make up for that lost by deposition upon the cathode.

In the former process the applied voltage (or E.M.F.) is lost in overcoming the internal resistance of the cell, and quantitatively is equal to the current multiplied by the resistance of the cell. In the latter process the applied voltage is greater than the above by the decomposition voltage of the solution.

In either case the voltage necessary for electro-plating processes is very low, usually from 1 to 6 volts; it is convenient to use a number of cells in series for these processes.

The rate of deposition of the metal on the cathode depends upon the current density, or, for a given area of surface to be coated, upon the current strength. For rapid plating, a high current is therefore required.

The following is the relation between the current strength

* *Also see*—

"Standard Handbook for Electrical Engineers," McGraw Hill Book Co.

"Electro-Metallurgy," W. G. McMillan and W. R. Cooper. (C. Griffin & Co.)

"Electro-plating and Electro-refining of Metals," Watts and Phillips.

An excellent series of papers upon electro-plating with various metals is given in *Trans. Am. Electrochem Soc.*, Vol. XXIII, p. 99, etc. O. P. Watts.

C amperes) and the weight of metal ($w$ grammes) deposited in a given time ($t$ seconds)—

$$w = C.e.t \text{ grammes}$$

where $e$ = the electro-chemical equivalent of the metal to be deposited
= the weight of metal deposited by a current of 1 ampere in 1 second.

Tables of electro-chemical equivalents for most common metals are given in works upon physics and chemistry.

The surface to be coated must be thoroughly cleaned, both mechanically and chemically. A solution or bath of caustic soda or caustic potash will remove grease, oil, fat, etc.

It is usual to employ acid solutions for cleaning copper, silver, zinc, iron, and brass surfaces; the following solutions are suitable for the purpose—

| | *Water.* | *Nitric Acid.* | *Sulphuric Acid.* | *Hydrochloric Acid.* |
|---|---|---|---|---|
| Copper .. | 100 | 50 | 100 | 2 |
| Silver .. | 100 | 10 | — | — |
| Iron .. | 100 | 2–3 | 8–12 | 2–3 |
| Zinc .. | 100 | — | 10 | — |

In order to obtain the proper adherence of the deposited metal it is necessary for the metals to alloy at their junctions, and some care is therefore necessary in selecting pairs of metals for plating processes.

For example, copper will satisfactorily alloy with iron or steel, but nickel will not, so that when iron or steel requires to be nickel-plated it must first be copper plated and then nickel-plated on top of the copper.

Nickel may be readily deposited upon brass, bronze, or copper (and upon most copper alloys).

Lead and most lead alloys require copper-plating before nickel can be deposited upon them.

In copper-plating, a copper sulphate solution containing

free acid may be employed; for small work a deposit of copper upon iron or steel may be obtained by immersing the cleaned metal in a copper sulphate bath.

The cyanide solution is now generally employed for copper-plating, and a good solution may be made as follows: Dissolve 20 grammes of copper acetate in 500 cubic centimetres of water, and in another 500 cubic centimetres of water dissolve 20 grammes potassium cyanide, 25 grammes sodium sulphite crystals, and 17 grammes sodium carbonate crystals. The first solution is then added to the second for use. A current density of 0·003 amperes per square centimetre is suitable for this solution, with a voltage of about 3 at the cell terminals.

In nickel-plating, the nickel salt frequently used is nickel-ammonium-sulphate.

The salt is dissolved by boiling 12 to 14 ounces per gallon of water and diluting to a specific gravity of 6·5 to 7·0 Beaumé; the solution should be slightly acid.

For plating zinc with nickel, a current density of 0·05 to 0·10 amperes per square inch is about correct; for copper and its alloys, a current density of 0·025 to 0·06 amperes per square inch is required. The addition of 0·125 ounce of benzoic acid per gallon of the solution improves the quality of the nickel deposit.

Another satisfactory plating solution* is the nickel sulphate one, containing a small amount of free citric or boracic acid. A current density of 0·005 ampere per square centimetre is recommended. The proportions of nickel sulphate suggested are 50 grammes of nickel sulphate to obtain ½ litre of solution; 20 grammes of citric acid are then dissolved in water and neutralized by means of caustic soda, and this solution is diluted to ½ litre and added to the nickel sulphate solution.

A voltage of about 3 is required for nickel-plating. Thicker deposits may be obtained from neutral or slightly acid nickel sulphate solutions heated to 70° or 90° C.

With a stronger solution containing from 150 to 350 grammes

* F. Foerster, *Zeit. f. Elektrochemil*, Vol. IV, p. 160.

of nickel sulphate per litre (and a little sodium sulphate), the current density may be increased to 0·02 to 0·08 amperes per square centimetre. With a good circulation of the electrolyte, deposits of 1 millimetre in thickness can be obtained.

In order to obtain the proper solution of the nickel in the electrolyte, cast nickel anodes should be employed in preference to those of the rolled metal.

It is also essential to obtain as large an area of anode as possible; for this reason corrugated nickel sheets are now employed, and the area of the nickel anode is made about 40 per cent. greater than that of the surface to be plated.

In order to obtain the best deposits it is necessary to avoid the formation of large crystals in the deposits, or the inclusion of foreign matter in the electrolyte solution. The size of the deposited crystals can be reduced either by increasing the current density or potential difference at the cathode, or by lowering the temperature.

The formation of "trees" may be prevented by a very small addition of a colloid which, under the action of the current, migrates toward the cathode and renders the deposit more uniform. Tree formation is facilitated by a high potential drop through the solution and by conditions favourable to the formation of large crystals.

Nickel plating is employed for protecting the steel and brass parts of aircraft and automobiles against rust; the deposit may be either matt, as in the case of small aircraft clips and fittings, or polished by buffing, etc., as in the case of bicycle handlebars, motor car radiators and accessories, where a good appearance combined with non-corrosive qualities is essential.

## NICKEL-ALUMINIUM

The surface corrosion of aluminium in exposed positions can be prevented by the electro-deposition of nickel. A commercial process now in use consists in first removing the

surface skin of the aluminium electrolytically by making it the anode, and by then reversing the current, using a nickel anode so that the aluminium is coated with nickel. It is claimed that this nickel skin will withstand any mechanical treatment which fails to rupture the original metal, and that all liability to corrosion is eliminated.

# CHAPTER V

# THE STRUCTURE AND PROPERTIES OF TIMBER

THE subjects of the physical properties and the mechanical strengths and testing of timbers are dealt with at some length in Chapter VI; it is proposed in the present chapter to briefly consider the internal structures of some of the typical woods, in order to illustrate the more common definitions and terms in use, and to describe a few of the woods employed in aeronautical and automobile work.

## THE STRUCTURE OF TIMBER

It is important, more especially in aircraft work, not only to be able to identify the different kinds of wood in use, but to tell from a microscopic examination, or with the aid of an ordinary magnifying lens, something of the previous history, treatment, and the quality of the timber.

It is outside of the scope of the present work to study these subjects in any detail, but for fuller information the reader is referred to the sources of information given in the footnote.*

## CLASSIFICATION

Botanically, trees are classified into groups according to their general characteristics, such as the flowers, seeds, and leaves. There are two principal classes of woods, namely:

* "Timber and Timber Trees," Laslett. (Macmillan & Co.)
"Timber and Some of its Diseases," H. Marshall Ward. (Macmillan & Co., Ltd.)
"The Mechanical Properties of Wood," S. J. Record. (John Wiley & Sons.)
"Wood and Other Organic Structural Materials," C. H. Snow. (McGraw-Hill Book Co.)
"Timbers and How to Know Them," Dr. Hartig and Dr. Somerville.
"Timber: Its Identification and Mechanical Properties," W. H. Barling. (*Journ. Aeron. Society*, May, 1918.)

(1) Gymnosperms, which yield naked seeds, and (2) Angiosperms, in which the seeds are always enclosed in seed-vessels or fruit.

The following table illustrates the subdivision of these classes and gives a few typical examples of each group or family.

## TABLE LXXVII.

### Classification of Woods.

| 1. GYMNOSPERMS. *(Naked fruit or seeds.)* | 2. ANGIOSPERMS. *(Enclosed fruit or seeds.)* |
|---|---|
| Subdivided into three classes, (*a*), (*b*), and (*c*).<br>(*a*) Cycadaceae.—Tropical and sub-tropical woods. Practically useless for commercial timbers.<br>(*b*) Gnetaceae — Under-shrubs, shrubs, and small trees, mostly of tropical origin. Practically useless for commercial timbers.<br>(*c*) Coniferae.—The seeds are borne on overlapping scales, arranged in cones. The leaves of ordinary species are narrow, rigid, needle-like, or scaly. Resins are present.<br>*Needleleaf, Softwood, Evergreen,* and *Cone-bearing Trees,* includes *Pines, Spruces, Firs, Cedars and Larches.*<br>(1) *Pines.*—Scots Pine, Shortleaf, Longleaf, Kauri, Loblolly, White, Yellow, Pitch, and others.<br>(2) *Spruces.*—Silver Spruce, Black Spruce, White Spruce, Douglas Spruce, and others.<br>(3) *Firs.*—Douglas, Silver, Red, Norway, Balsam, and others.<br>(4) *Cedars.* — Deodar, Lebanon, Atlas, Pencil, Red, White, and others.<br>(5) *Larches.* — European, Tamarack, and others. | Subdivided into two classes, (*d*) and (*e*).<br>(*d*) Monocotyledons. — Having one seed leaf or cotyledon. The veins in the leaves are more or less parallel. Some 25,000 species have been identified.<br>This class includes the non-banded trees such as the *Palms* and *Bamboos.*<br>(*e*) Dicotyledons.—Having two seed leaves. The veins in the leaves are netted. The stems of these plants increase by layers of new material forming upon the outside of the earlier ones. Includes over 100,000 species, only a few hundreds of which are of commercial interest.<br>This class includes the Broad-leaf, Deciduous, or Hardwoods of Commerce.<br>*Examples*—<br>Oaks, Birches<br>Ashes, Elms<br>Maples, Walnuts<br>Hickories, Mahoganies<br>Beeches, Poplars |

The *Non-Banded* trees, which include the palms and bamboos, contain the wood elements in separate bundles, so that in cross-section the trunk appears dotted.

The *Banded* trees contain the wood elements in the form of concentric layers, forming annual rings ; all of the commercial coniferous and hardwoods come within this category.

## INTERNAL STRUCTURE OF BANDED WOODS

The roots of a tree grow in length and in width, the linear growth occurring only at the end of the root ; it is termed " apical " growth.

The apex of the root is of *cellular structure*, each cell (Fig. 51) consisting of a firm elastic thin film band around the central *nucleus*, surrounded by *protoplasm* ; the outer boundary is composed of a carbo-hydrate known as *cellulose*. The protoplasm

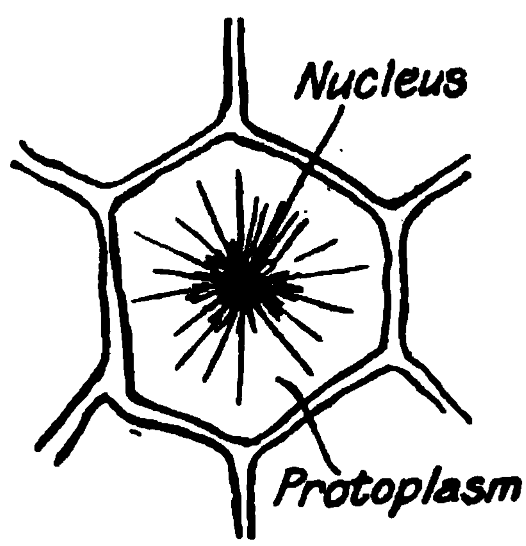



FIG. 51.

inside the cell is a jelly-like substance and comprises the living part of the tree.

The cells are not isolated, but communicate with each other, and the constituent cells do not grow in size as the tree grows, but divide up into other cells.

The cells become larger below as they recede from the root or apex.

### The First Year's Growth.

If the stem of a tree be examined in its first year of growth it will be seen to consist of : (*a*) the bast, consisting of tubular vessels ; (*b*) the wood, consisting of isolated fibres ; and (*c*) the cambium, or creative layer, as depicted in Fig. 52. The wood proper consists of cells with their sides of wood.

At the end of the first year the wood material fibres, after having been grouped in bundles in the summer months, become disposed in radial wedge-form, separated by *pith rays*, as shown in Fig. 52. The centre portion of the trunk of a tree, which represents the first year's growth, is termed the *pith*, and is usually in the form of a solid cylinder of soft material.

The cambium layer in successive years forms what is known as the secondary wood, which comprises practically all of the new wood formed in the tree ; this layer occupies the region between the sapwood and the bark, and consists of a thin-walled formative tissue, within which, by cell-division, growth

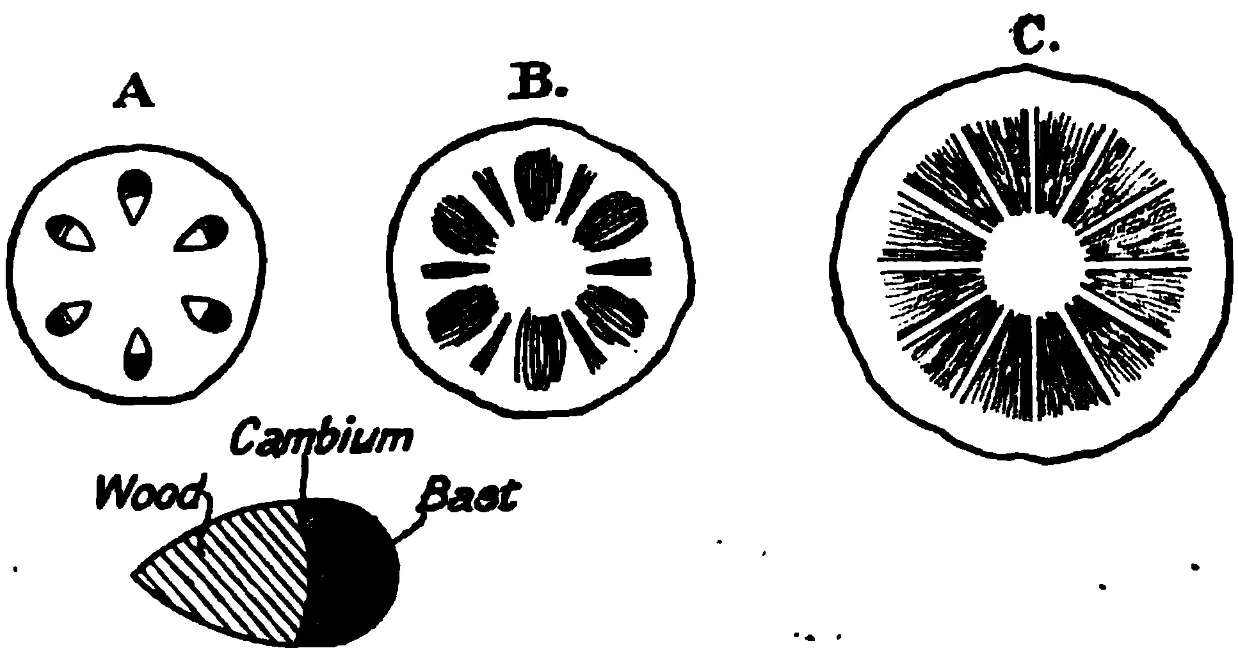



FIG. 52.—ILLUSTRATING THE GROWTH OF A TREE.

and modification, all of the wood elements originate. The cambium layer originates from the food materials, which are formed in the leaves, from the carbon-dioxide of the air, and which descends from the leaves to the growing part, where the new wood is formed ; the embryonic cells, previously mentioned, form the cambium layer, and these cells, by sub-division and growth (to full cell size), eventually form the new layer of wood at the inner side, whilst those at the outside form the *bark*.

The wood-cells, which are at first soft and delicate, become harder, due to the deposition of a substance known as *lignin* within their walls.

If the cross-section of a banded tree be examined (Fig. 53) it will be found to consist of an inner softer core of pith, surrounded by a number of concentric annular rings, each of which represents a year's growth, and known as the *annual rings*, at the outermost of which is the cambium layer and the *cortex* or *bark*, consisting of cork and softer tissues.

A number of radial lines will usually be seen in the cross-section, cutting across the annual rings at right angles ; these

FIG. 53.—SHOWING ANNUAL RINGS, DARKER HEART, AND LIGHTER SPRING WOOD AND BARK (PINE).

are known as the *Medullary Rays*, and they consist of narrow, vertical plates cutting the concentric annual ring sheets.

These medullary rays, or *pith rays* as they are sometimes termed, consist of a different kind of tissue to that which they traverse, and they serve as a vital link between the living elements of the tree, in the radial transmission and storage of the food. Medullary rays are planes of weakness and decay in timber, and when dead contain no starch.

These medullary rays, which are shown, magnified, in

Fig. 54, are composed of cells, cubical or oblong in shape (shown at M, Fig. 54) and indented with minute pit-marks.

The presence of medullary rays gives to many woods (for example, oak and beech) their characteristic appearance.

## WOOD ELEMENTS

The term "wood element" includes the different fibres and vessels of which wood is a constituent, such as the *wood fibres*, *wood parenchyma*, *tracheids*, and *medullary rays*.

Reverting for a moment to the example shown in Fig. 53, it will be seen that each of the annual ring layers consists of inner lighter portions and outer darker portions, corresponding to the *spring* and *autumn* woods respectively.

FIG. 54.—SHOWING MAGNIFIED APPEARANCE OF SPRING AND AUTUMN WOOD.

If this layer be examined under the microscope, it will be found (in the case of a conifer) to have the appearance shown in Fig. 54; the spring wood consists of the larger

partitions or cells, and the autumn wood of the flattened, more compact cells which cause the wood to appear darker, relatively, to the spring wood.

In the case of the spring wood the walls of the cells or vessels are thin, whilst in the autumn wood they are thick, and the passage through them is consequently small; the autumn wood, with its closer structure, always abounds the annual ring.

The differences between the spring and autumn vessels is due to the relatively greater growth activity in the spring and summer months, during which the cambium cells begin to divide and multiply, whilst in the winter, when there are few if any leaves to supply food and the roots are almost inactive, the cambium ceases to be active, so that little material is added.

Fig. 55 shows a micrograph of longleaf pine, in which several growth rings can be seen. The dark-coloured bands denote the late wood, and the seven cavities are resin ducts.

A closer examination of the vessels shown in Fig. 54 will reveal the presence of a number of thin places in the walls known as " pits," or " bordered pits," which in cross-section have the appearance shown in the magnified diagrams, Figs. 56, 57, and 58.

The bordered pits, or windows, are always found on the radial walls, and so in radial sections of the trunk these pits will appear as circular patches in the tracheids, or wood cells, and as elliptic or oval shapes with thin walls in longitudinal tangential sections; the pits materially assist in the conduction of water from the roots to the leaves, through the stem.

The cells shown in section in Fig. 57 are actually elongated in shape, with needle-like ends, being the older cells of the tree in which the walls have become thickened by the deposition of lignin, to which substance the hardness of wood is due; the cell protoplasm has also disappeared.

These elongated tapered cells are termed *tracheids*, and

Fig. 55.—Micrograph of Longleaf Pine, showing Four Annual Rings, and Seven Resin Ducts. Magnified 24 Times.

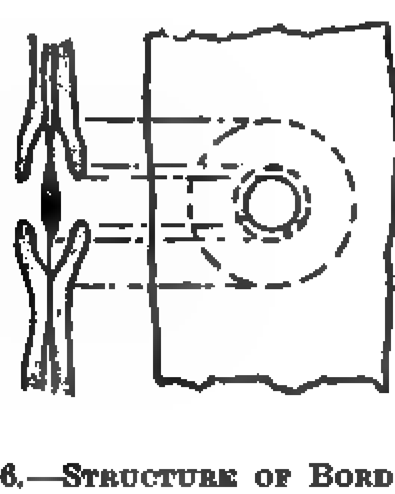


Fig. 56.—Structure of Bordered Pit.

they serve to convey water and air, and to contribute to the mechanical strength in the coniferous woods. These tracheids are characterized by peculiar markings on their surfaces, including bordered pits, and ridges of various forms; in the case of broad-leaved or dicotyledon trees these tracheids are often marked spirally or in a zig-zagged manner.

Fig. 57.—Showing Bordered Pits (*b*) and (*c*). The Arrow denotes the Direction of the Centre of the Stem.

Fig. 58 illustrates, in three dimensions, the microscopic structure of a piece of spruce fir,* and it clearly shows the tracheids of the autumn wood, to the right, and the spring wood, to the left, with bordered pits (shown by the circular patches) on the walls of the spring tracheids.

The constitution of the medullary rays, *n m*, running radially between the tracheids is also clearly shown in cross section and in tangential and side elevation.

The living part of the wood on the outside of the tracheids

* After Hartig.

consists of cells filled with sugar and starch, and is termed the *parenchyma*.*

***Wood fibres*** are long, slender, comparatively smooth-surfaced and pointed wood elements, the walls of which are thick and contain lignin, and the pits are usually of the simple, as distinct from the bordered, type.

1 2

FIG. 58.—SPRUCE-FIR IN SECTION.

Wood fibres are not found in coniferous wood, but are almost invariably found in the dicotyledons, such as oak, ash, hickory, etc., and are largely instrumental in contributing to the strength and hardness of these woods. In the case of many coniferous woods, certain intercellular passages, considerably larger than the ordinary cells or vessels, occur, usually in

* In practice it is the truly dead part which is used, for if parenchyma cells are alive, the walls are thin and fungus grows on them.

scattered positions, as shown in Fig. 55; these passages are known as *resin ducts* or *canals*.

**Dicotyledon Structure.**

All ordinary woods resemble each other in their general properties of being made up of cells, cambium layers, and wood elements, but they differ individually in the arrangement of these constituents; for example, in some cases the wood elements are arranged up and down parallel to the axis of the trunk, whilst in other cases they are sinuous, wavy, or twisted.

FIG. 59.—SHOWING TYPICAL DICOTYLEDON STRUCTURE (BARK).

The broad-leaved group, comprising the oak, ash, beech, chestnut, poplar, etc., resembles the coniferous group in showing bark, annual rings, pith, and medullary rays, but differs in details.

One distinguishing feature of most of the hardwood series, which is clearly indicated in cross-sections similar to that shown in Fig. 59 is that of the number of relatively very large

openings, known as *vessels**, which occur. These vessels, which are not found in conifers, are formed by the breaking down of the intermediate layers between the cells, so that a continuous passage is left.

These long tubular structures exhibit pits and markings similar to tracheids, the contents being water and air.

Each vessel may be regarded as a tube made by the joining of a long vertical row of tracheids, between which are the much more numerous elements with small lumina and thick walls, the latter being the wood fibres proper.

Each fibre is in effect a tracheid with much thicker cell walls than usual, and devoid of the characteristic bordered pits. In the case of dicotyledons, rows of shorter cells, scattered in small groups, occur; these are termed *wood parenchyma*, and they are often found near the vessels. They are produced by the cambium cell becoming divided across into several superposed short cells or chambers, which retain their living contents, and they closely resemble the medullary ray cells in other respects.

## Heartwood and Sapwood.

The central stained wood in a tree is termed the *heartwood*, whilst that of the lighter outside wood is termed *sapwood*. The difference in colour is very marked in some cases, as in the oak and ash, whilst in others it is hardly perceptible. All wood cut off by the cambium layer is lightly coloured at first, and with time it becomes darker and less liable to decay; the darkening is due to the walls of the cells becoming stained or saturated with colouring matter such as tannin, which, being antiseptic, protects it from the attacks of insects and fungi. The vessels of the heartwood become plugged up with gum, and the parenchyma cells, by diosmosis, set up great pressures, which burst the weaker sides of the vessels and block up the vessels. The parenchyma loses its starch,

* These should not be confused with "resin ducts."

protoplasm, etc., and becomes filled with a substance offensive to insects and fungi.

Sapwood is a new wood, and its chief functions are to conduct water from the roots to the leaves and to store up and give back, at the appropriate period, the food prepared in the leaves. The volume of the sapwood will be greater the more leaves the tree bears, and the more light they obtain ; for this reason forest-grown trees have less sapwood than open-grown wood of the same kind.

Some species form heartwood very early in life, whilst in others a considerable period of time is required.

In the case of certain woods (for example, chestnut, Scots pine, and mulberry) the sapwood is thin, whilst in the case of ash, maple, beech, and hickory it is relatively thick.

As a tree grows the sapwood becomes thinner, and it is thicker in the upper portion of the trunk than near the base, since the age and diameter of the upper sections are less. The sapwood of an old tree, especially in the case of a forest-grown tree, is freer from knots than the heartwood, as the branches of the young tree are more numerous, and these, dying off at an early stage, give rise to knots in the early or heartwood.

Certain trees, such as spruce and silver-fir, do not produce heartwood, but the wood remains the same colour throughout and is termed *ripewood.*

*False heartwood* is the name given to the darker central wood of some trees which has been produced by disease ; it can be readily distinguished from the true heartwood, owing to its irregularity in shape and to the darker portions not conforming to the shape of the annual rings.

## IDENTIFICATION OF CONIFERS.

The table on page 194 shows the distinction between the more common conifers.

The pines are distinguishable from the larch in the disposition of the branches in longitudinal section. In the case of

the pines the branches radiate from the same level so that all of the knots, corresponding to a group of branches, are at about the same vertical level, whereas in the case of the larch the branches are alternate, and the knots each occur at vertical intervals. The pines are not suitable for long struts, owing to the weakness at the line of knots.

TREES.

- No Vessels (Conifers)
  - Heartwood
    - Resinous — *Pines.* (including Baltic Scots, and Larch)
    - Non-Resinous — *The Yew.*
  - No Heartwood
    - Resin Ducts — *The Spruce.*
    - No Resin Ducts — *Silver Fir.*
- Vessels Broad-leaved trees, or Dicotyledons.

**General Identification of Trees.**

It is not possible to deal more fully with the subject of the identification of woods here, and the reader seeking further information is referred to the works* dealing with this subject; the Table† shown in Fig. 60, however, will afford some introductory information upon this subject.

## THE SEASONING OF TIMBER

**Moisture Content.**

Timber in the green state contains solid matter or wood substance, salts, water, and air, and its weight or density depends upon the relative proportions of these constituents. The wood substance of all trees has the same specific gravity, namely, 1·555, so that the differences in the densities of the

* See p. 181.

† From "Timber, Its Identification and Mechanical Properties," W. H. Barling, *Aero. Journ.*, May, 1918.

various timbers when dry will depend upon the relative proportions of wood substance volume to total structure volume.

The effects of moisture and density upon the mechanical properties of timber are considered in Chap. VI, and the

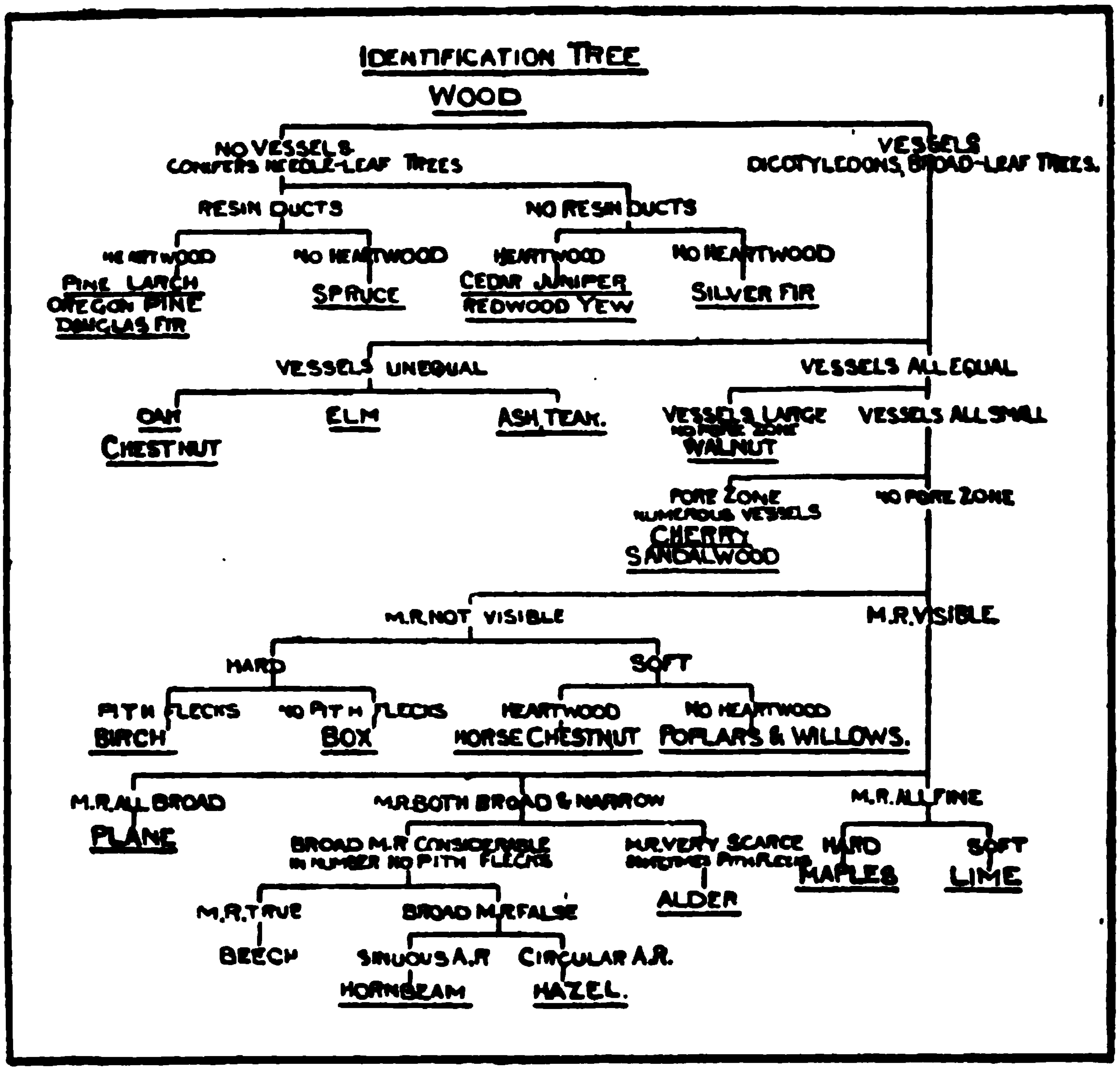



FIG. 60.—GENERAL IDENTIFICATION DIAGRAM FOR COMMERCIAL WOODS.

present remarks will therefore be confined to the physical and practical sides of the subject.

Water occurs in green or living wood in three principal conditions, namely: (*a*) As free water in the cell spaces; (*b*) in the cell walls; and (*c*) in the living cells themselves, in the protoplasm.

In the sapwood the water occurs in all of these conditions, so that the maximum amount of water is found in this part of the tree ; more than one-half of the weight of the green sapwood may be due to water.

In the heartwood, water only occurs in conditions (*a*) and (*b*), and the percentage moisture content is therefore less than in the case of the sapwood.

When wood is oven or kiln dried, it retains from 8 to 16 per cent. of the water in the cell walls, and practically none in conditions (*a*) and (*c*) ; no wood can be absolutely dry, some water being always present.

The ordinary air-dried timber of commerce contains from 4 to 12 per cent. of its weight of water ; for this reason it is necessary to specify the moisture content in connexion with the density of timbers.

## SEASON OF FELLING

Timber should be felled in the winter, when the sap is down and when the growth activity is at a minimum. Wood dries more rapidly in summer than in winter, and is therefore more liable to shrink if felled in summer, and if the shrinking is too rapid, checks, splits, or defects occur.

In cold weather, drying occurs at a slower and more uniform rate, and a better seasoned timber results ; moreover, there is less danger of attack by insects and fungi (or sap-rot) in the cold weather.

If timber could be cut up into lumber immediately after felling, and artificially dried, there would probably be no difference in the quality or shrinkage effects, whether summer or winter felled.

## SEASONING

The process of seasoning timber consists in drying out most of the moisture, for wet timber, apart from its greater density and lower mechanical strength properties, is very liable to the attacks of insects and fungi.

The strengthening effect of drying does not become evident until the free water is evaporated and the cell walls begin to dry; at this stage the degree of moisture is known as the *fibre-saturation point.*

In green wood the cells are all connected together and are at their natural size when saturated with water; as the wood dries the water films between the cell wall particles becomes thinner and thinner, and as a result the cell walls grow thinner and shrink.

This shrinkage in the whole wood is unfortunately not uniform in all directions (although in some seasoning processes the effect is minimized) and gives rise to cracks or splits.

A rod of green wood shrinks radially, tangentially, and longitudinally by different relative amounts as follows—

(1) Radially by 3–5 per cent. of the original radius.

(2) Tangentially by 6–15 per cent. of the original tangential length.

(3) Longitudinally by 0·1 per cent. of the original length.

As the tangential shrinkage is the greatest, and also owing to the weakness of the medullary rays, logs of timber, when dried, crack tangentially; that is, they exhibit radial cracks as shown in *A*, Fig. 61.

Diagrams *B*, *C*, and *D* show the manners in which timber cut from logs shrinks or warps in consequence of the relatively greater tangential shrinkage.

It will be observed from (*B*) that the diametrical plank does not actually warp, but shrinks at the outer radii, whilst preserving its general flatness.

Air-dried wood is hygroscopic and does not cease to warp.

The heartwood o' a tree, having a lower moisture content, shrinks and warps less than the sapwood; in general the heavier the wood the greater the amount of warping during drying. In fir wood, the water ejected from the wood on drying can be replaced by the resin, and therefore it warps less.

The following list shows some of the coniferous woods in

their relative order of warping, the lower numbers corresponding to those woods showing the least warping effect.

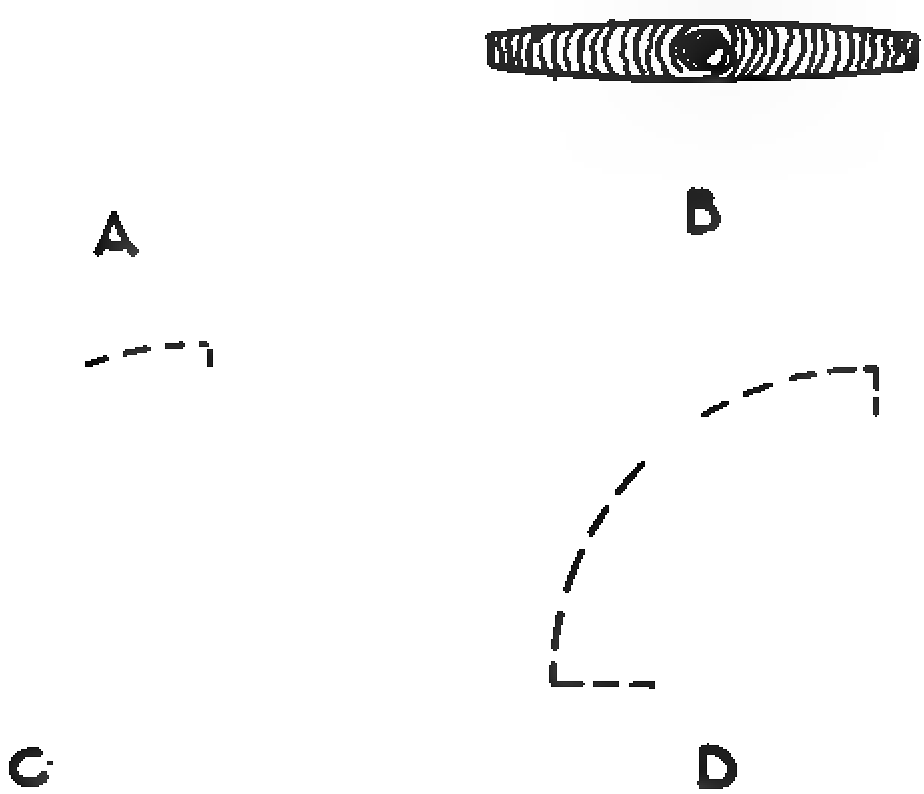



Fig. 61.—Showing Shrinkage of Timber on Drying.

## TABLE LXXVIII.

### Relative Warping of Coniferous Woods on Drying.

| *No.* | *Wood.* | *Remarks.* |
|---|---|---|
| 1 | Pitch pine | Most resinous |
| 2 | Weymouth (Amer. white pine) | — |
| 3 | Scots pine (Dantzic & common fir) | — |
| 4 | Spruce | — |
| 5 | Silver fir | Least resinous |

In the ordinary method of air seasoning, drying occurs from the outside inward, the central portions remaining the moister, so that the shrinkage is not uniform; in the better kiln-drying processes, drying is rendered more uniform by first heating the wood in a moist atmosphere before drying. The result of ordinary drying methods is to leave a harder dry shell with a softer moist interior, the condition being termed "case-hardened."

The drying effect, in the case of a log is greater at the sawn ends, due to the ends of the cells and vessels being open; for this reason logs and long poles are apt to split at the ends, but in many seasoning processes the moisture is evaporated through the ends.

The wood cells do not shrink appreciably in length, but in cross-section considerable shrinkage occurs, leaving the cells smaller in cross-section and with thinner walls; the shrinkage is more irregular for this reason, for wherever the cells cross one another at any angle there is a tendency to pull apart, more especially in places where the wood fibres and medullary rays meet.

The medullary rays shrink in height and in width, but do not shrink appreciably in length, or radially; these rays, for the above reasons, are always regarded as planes of weakness in timbers.

The tendency of logs to crack and split may be to a large degree prevented by cutting them into planks at an early stage, for the smaller the section or thickness of timber, the less is the tendency to split or crack.

It is now customary to use S-shaped thin steel clamps as shown in Fig. 62 to prevent logs from cracking; these clamps are driven into the butts of timber so as to cross incipient checks and to prevent their widening; these clamps should be driven into position when the splits first appear.

To prevent cracks in the ends of boards, small straps of wood are sometimes nailed to them, the grain being at right angles to that of the boards; this method is also employed

to prevent small planks of valuable or special timber from warping.

Timber which is cut up into the form of planks and seasoned is sometimes varnished or rough French polished to prevent it from warping; in some cases the ends are dipped into melted paraffin wax to prevent loss of moisture there.

Other methods of sealing the ends of special timber are to use glued paper, grease, carbolineum, wax, linseed oil, tar, or petroleum.

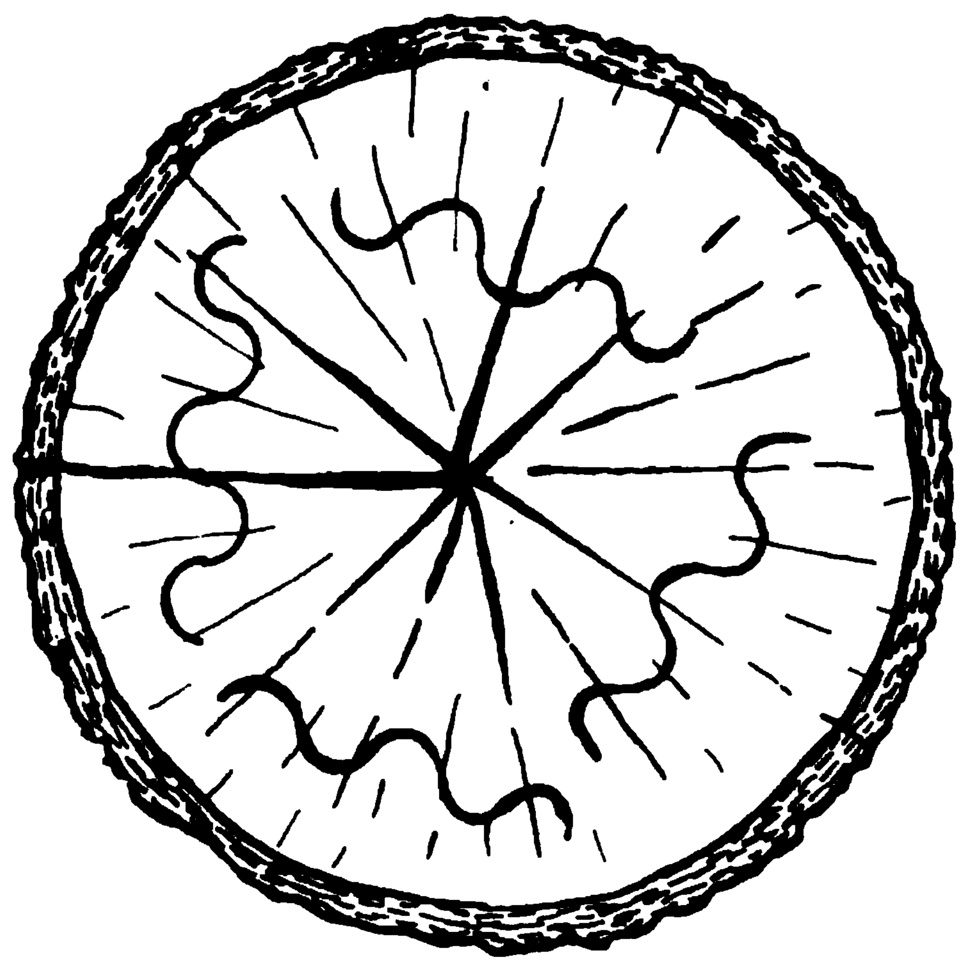


FIG. 62.

## METHODS OF CUTTING TIMBER

The different methods of cutting timber are shown in Fig. 63, and in this connexion it should be noted that radially cut boards or planks shrink less than those cut tangentially. When timber is sawn tangentially to the annual rings it is said to be *flat sawn*, as shown in diagram *A*, Fig. 63.

When timber is sawn so that the annual rings are cut in a radial direction, it is said to be *rift* or *quarter sawn* (diagram *B*, Fig. 63).

In the former case the boards possess *flat grain*, and in the latter case *edge, straight,* or *vertical grain.*

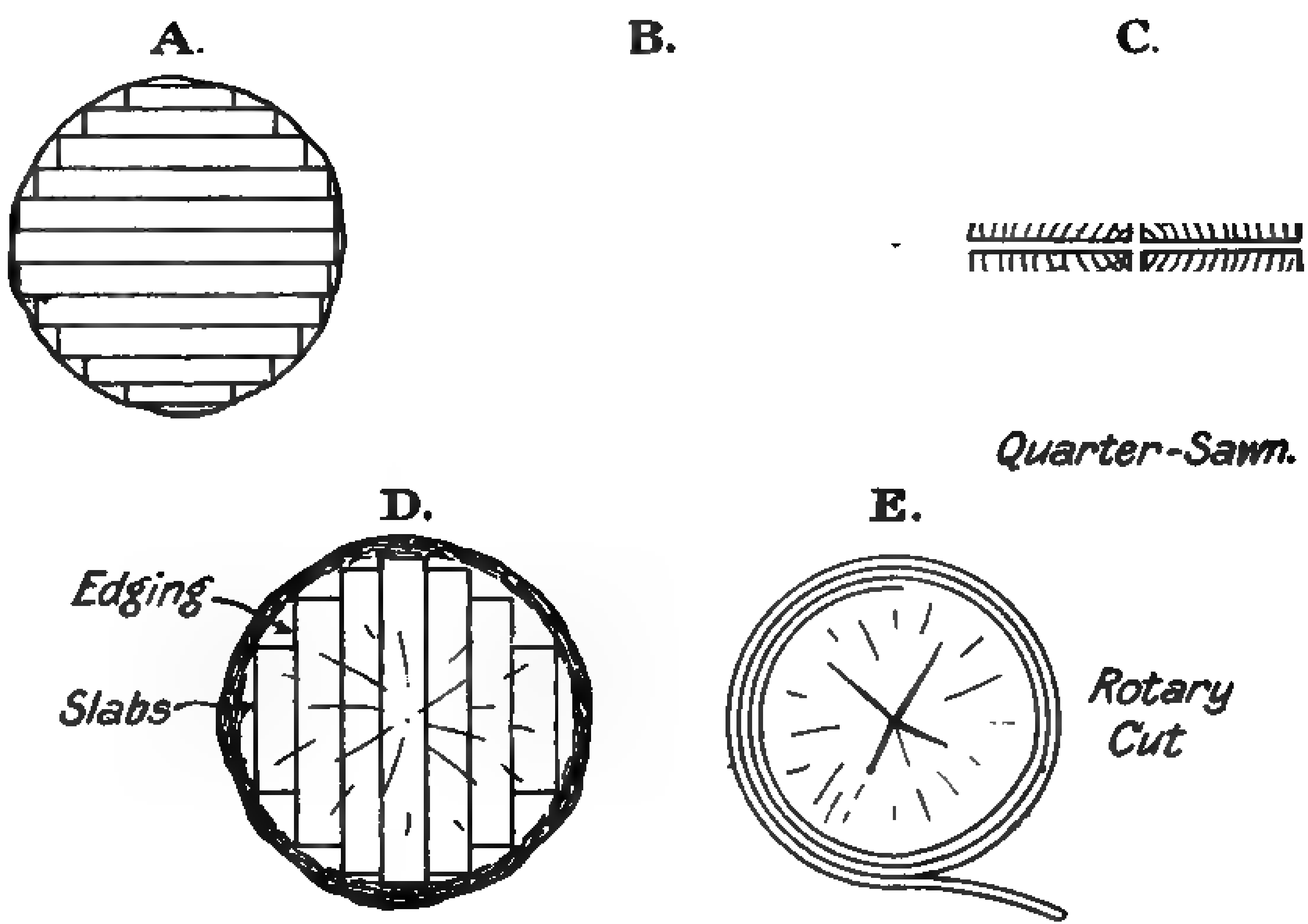



FIG. 63.—ILLUSTRATING METHODS OF CUTTING LOGS.

Rift-sawn planks show much better grain effects, and wear more evenly; the timber also does not shrink so much.

*Quartering* timber consists in sawing it, by radial cuts, into quarters; the pith or medullary rays are exposed, in the case of woods such as oak, by this process, and the method is used for decorative panel and similar work. (Diagram *C*, Fig. 63.)

The best grain effects are often obtained when pieces are *rotary cut*, as shown in (*E*), Fig. 63; that is to say, peeled, peripherally, with sharp knives or fine saws, as in the process of veneer making. Walnuts, mahoganies, and bird's-eye maple give very fine grain effects and are much used for veneer work.

Ordinary planks are cut parallel to the diameter of the trunk, as shown in (*D*), and these warp more and show less grain effect than those rift sawn. Most building and constructional timber is cut in this manner.

The uneven appearance of the edges of boards which have been cut through from one side of the log to the other is known as *wain.*

*Edging* refers to uneven pieces or edges that are removed when the boards are cut down to standard widths.

*Slabs* are segments of bark and sapwood removed from the outside when the logs are sawn diametrically, as shown in Fig. 63 (*D*).

## DEFECTS IN TIMBER

The defects which occur in timber may be divided into three principal classes, namely: (1) Cracks, (2) Knots, and (3) Insect and fungus actions.

There are several types of cracks or shakes which occur in timber due to mechanical action, shrinkage, wind, and weather action; some of these are shown in Fig. 64 (A to F).

*Heart* and *star shakes* (*A*) and (*B*) are radial cracks extending from the centre outwards, and are due to shrinkage of the annual rings; the former term is usually applied to a single radial crack and the latter to several radial cracks.

*Cup shakes* (*C*) in town-grown trees may be due to abrasion by animals carts, etc., which causes the cambium layer to be killed locally, so that the peripheral layers separate. A species of cockroach (termites) also produces this effect in tropical regions.

*Wind shakes* (*D*) are cracks produced by the bending action of the wind and occur as radial and peripheral cracks.

A. B. C.

D. E. F.

FIG. 64.

*Ring shakes* are splits which run completely around the circumference ; they are produced by frost action due to the expansive force of the melting ice in the cells, and by fungi.

*Checks* are the deep small cracks which appear in planks and logs which have been dried too rapidly.

*Knots* are distortions or interruptions of the annual layers, caused by the outward growth of branches. Initially, the buds are connected with the pith cavity at the centre, later these appear at the surface and develop into branches, with

the result that the annual layer formation of the main stem is locally disturbed. Knots may be prevented by removing the buds when they first appear.

In the case of the pines, the branches all grow at the same horizontal level, so that boards and struts of the timber cut longitudinally are weak. In the case of larch, the branches alternate, and this timber is suitable for struts and pit-props.

FIG. 65.—SHOWING FORMATION OF A KNOT.

The following are the definitions of the different kinds of knots, recommended by the American Society for Testing Materials—

(1) SOUND KNOT.—A sound knot is one which is solid across the face and which is as hard as the wood surrounding it; it may be either red or black, and is so fixed by growth or position that it will retain its place in the piece.

(2) LOOSE KNOT.—A loose knot is one not firmly fixed in place by growth or position.

(3) PITH KNOT.—A pith knot is a sound knot with a pith hole not more than one-fourth inch in diameter, in the centre.

(4) ENCASED KNOT.—An encased knot is one which is surrounded wholly or in part by bark or pitch. Where the encasement is not less than one-eighth of an inch in width on both sides, not exceeding one-half the circumference of the knot, it shall be considered a sound knot.

(5) ROTTEN KNOT.—A rotten knot is one not so hard as the wood it is in.

(6) PIN KNOT.—A pin knot is a sound knot, not over ½ inch in diameter.

(7) STANDARD KNOT.—A standard knot is a sound knot not over 1½ inches in diameter.

(8) LARGE KNOT.—A large knot is a sound knot, more than 1½ inches in diameter.

(9) ROUND KNOT.—A round knot is one which is oval or circular in form.

(10) SPIKE KNOT.—A spike knot is one sawn in a lengthwise direction; the mean or average width shall be considered in measuring spike knots.

FIG. 66.—ILLUSTRATING VERTICAL AND HORIZONTAL STACKING, FOR NATURAL SEASONING.

## SEASONING PROCESSES

There are three principal methods of seasoning timber, namely: (1) Natural or air seasoning, (*b*) Water seasoning, and (*c*) Artificial or kiln seasoning.

### Natural Seasoning.

This process consists in stacking the timber in the open air, and allowing it to dry naturally, the water being expelled gradually and shrinkage occurring uniformly.

It is not possible to season some woods by this process, but for the great majority of commercial timbers it is suitable.

The process takes from two to four years to complete, and for this reason it is not employed where timber is required as soon as possible after felling.

It is necessary to stack the planks with intervals between each so that the air can circulate all around, and with a roof or covering to exclude rain; close piling not only retards the rate of drying but encourages rot; in some cases the stacked timber is re-arranged so that the inner planks, which have not dried so much, replace the outer and drier ones.

Wood for musical and mathematical instruments, and for the better classes of furniture, is invariably air-seasoned, the process taking several years.

In some cases timber is given a preliminary soaking in water before air-seasoning, whilst in others the air seasoning is stopped at a certain stage and completed by the artificial method.

### Water Seasoning.

This method consists in storing the timber, usually in the form of logs, under water, for it is well known that the wood will retain its good properties, and in many cases will gradually improve, for very long periods.*

Logs stored under water do not crack or rot, and when they are removed to the open air dry more rapidly than green timber; for this reason the process of water seasoning is sometimes combined with that of air seasoning.

The water acts not only by excluding the air, but by dissolving out the impurities in the timber, rendering it more durable and less liable to warp.

### Artificial Seasoning.†

A very large proportion of commercial timber is now dried by the kiln methods, more particularly in the case of the

* Bog-oak is an example of this.

† For fuller particulars see "Wood and Other Organic Structural Materials," Snow; "The Preservation of Wood," A. J. Wallis Taylor, *Journ. Roy. Soc. Arts*, 20th Feb., 1914; "The Artificial Seasoning of Timber," Prof. G. Groom, *Proc. Inst. Autom. Engrs.*, Jan., 1918.

hard-woods. The advantages of kiln drying lie in the rapidity of the process and in the possibility of controlling the various factors influencing the correct seasoning results.

The three principal factors concerned in these methods are: (*a*) The temperature of the process, (*b*) the moisture, and (*c*) the circulation.

Properly chosen kiln processes aim at controlling the rate and degree of drying, so that the tendency during drying to warp and split is reduced to a minimum. In several kiln drying methods the loss of moisture from the surface, which would otherwise be much greater than that from the interior and would cause uneven shrinkage, is met by a steady capillary current of water from the inside, so that the shrinkage is much more uniform.

In the best kiln processes this condition is approximated to by first heating the wood in steam, or a moist atmosphere, before allowing drying to begin.

The temperature of drying should not be much higher than from 100 to 120° F. in the case of green oak and similar woods which would lose certain of their volatile constituents if heated much above these temperatures. In the case of pines and cedars, temperatures of from 140° to 180° F. are generally employed.

Wet heat (that is, steam) adds to the moisture and assists in keeping the surface soft and swollen until the heat has penetrated to the interior, so that warping and checking are prevented. It is necessary to maintain a constant circulation of the drying air, or steam, in the kiln, so that the drying occurs uniformly over the whole of the contents.

The circulation may be natural, that is to say, by utilizing the differences in density of hot and cold air connection, drying currents may be utilized, or it may be assisted or maintained by means of blowers and fans.

The timber to be dried may either remain stationary and the moist air circulate around it, or it may progressively move so that initially the green timber is situated near the

entrance where the air current contains most moisture, and finally it emerges from the other end of the kiln, where the air contains least moisture.

Many processes utilize the heat of steam-pipes, either placed vertically below the stacked timber, so that the heated air circulates naturally, or in the form of steam coils through which the drying air is forced by means of fans.

## Progressive Seasoning Method.

The progressive system* of seasoning timber consists in stacking the wood in a train of cars, which advance on rails periodically, usually 6 feet each day, in their progress from the loading ends of the drying tunnels, where the cars of wet wood are introduced, towards the discharging end, where seasoned wood is taken out. This method allows constant regulation of the conditions of the dryer as regards circulation, temperature, and humidity of the air.

The cars advance through the successive stages of the drying process, which is thus automatically graduated, and beginning in very moist air, the drying proceeds in slowly increasing temperatures and slightly decreasing humidity, but moist air is used throughout to prevent splitting, scaling, honeycombing, and other defects.

In general, there is one tunnel for hardwoods and one for softwoods. The tunnels may be of any required capacity, and in one large plant of this type at a ship-yard, the drier is 200 feet wide and is divided into a large number of progressive tunnels. The method of keeping the whole kiln full of wood in process of being treated is very economical and rapid.

The drying agent employed is low pressure steam, usually raised from wood refuse as fuel in a suitable boiler; the latent heat of the steam is transferred to the circulating air while the heat of condensation is returned by a pump to the boiler.

* Employed by Messrs. Eriths' Engineering Co., London.

The method of controlling the circulation consists in introducing at the loading end a small amount of outside air, in order to chill the air at the point where it is most saturated with moisture, and by discharging to the atmosphere such air as is wholly saturated. In this manner a rotary circulation of moist air is obtained without any special devices, and the bulk of the air is re-circulated and re-heated on its upward travel through the steam radiators, which are situated below the rail level.

This progressive system has been largely employed for drying all kinds and dimensions of native hardwoods and softwoods for aeroplane parts, automobile spokes, and ash felloes for artillery wagons.

The process occupies about 10 days in the case of softwoods, and a few weeks for ash, walnut, mahogany, and other hardwoods.

### Other Kiln Processes.

It has only been possible to describe one of the many artificial seasoning processes, but there are several other methods, usually based upon the same principles of employing steam or moist air, in vogue.

Several instances have occurred in practice, however, of too-rapidly dried timber warping or splitting after being fitted in position, or being in use for some time, and some care is therefore necessary in employing kiln-dried timber, to ensure in all cases that it has been properly seasoned.

### Effect of Seasoning Processes upon Properties.*

Table LXXIX shows the effects upon the bending and compression strengths of ash and pine†, when subjected to the action of air, moist and dry steam for different periods of time. In the columns headed "compression" and

* Also see "The Artificial Seasoning of Timber," P. Groom; *Proc. Inst. of Aut. Engrs.*, Jan., 1918.

† For the effect of moisture content upon the properties of spruce, see Figs. 74 and 75.

"bending" are given the percentage changes in strength as compared with those of naturally seasoned wood of the same moisture content.

The columns headed "dry" refer to wood which was first naturally seasoned and then subjected to the particular treatment indicated, and finally, naturally seasoned for one year before testing. The columns headed "soaked" refer to wood which was naturally seasoned, then soaked in water, and in this wet condition was subjected to the treatment indicated, and subsequently tested after a year's natural seasoning.

The results of these tests may be summarized as follows—

Exposure to a temperature of 145° F., with dry air or exhaust steam, for 19 or 26 days had little effect on the compressive or bending strength of the two timbers. An additional couple of days in exhaust steam or an additional eight days of dry heat at 170° F. evoked signs of weakening.

Shorter exposures to saturated steam at 212° F. (for up to four hours) or superheated steam at atmospheric pressure at temperatures 274° F. and 331° F. (for four and six hours respectively) caused no injurious effects.

But immediately that saturated or superheated steam at high temperatures, with the pressure at 30 pounds or more, is applied, weakening of the timbers quickly ensued. In saturated steam at 274° F. at a pressure of 30 pounds, pine was in four hours weakened about 10 per cent.; at 331° F. and 90 pounds pressure, ash was in five minutes weakened 4 per cent., and in one hour 27 per cent.; while the pine was weakened 9 per cent. in fifteen minutes and 42 per cent. in four hours.

But when the ash was subjected in its soaked condition to saturated steam at 331° F. with the pressure at 90 pounds, no ill effects resulted; yet under the desiccating influence of superheated steam at the same temperature, but at atmospheric pressure, a weakening took place.

The significance of these results, particularly in relation to

## TABLE LXXIX.

### Effect of Seasoning Processes upon Strength.

(U.S. Forest Service.)

| *Nature of Treatment.* | White Ash. | | | | | | Loblolly Pine. | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Temperature, ° F.* | *Duration of Treatment.* | *Compression, Dry.* | *Compression, Soaked.* | *Bending, Dry.* | *Bending, Soaked* | *Duration of Treatment.* | *Compression, Dry.* | *Bending, Dry.* |
| Dry air .. .. .. | 145 | 25 days | (*c*) | (*c*) | (*c*) | (*a*)5 | 26 days | (*c*) | (*b*)2 |
| Dry air .. .. .. | 170 | — | — | — | — | — | 8 days* | — | (*b*)6 |
| Dry air .. .. .. | 200 | — | — | — | — | — | 3 days* | (*c*) | (*b*)5 |
| Dry air .. .. .. | 250 | — | — | — | — | — | 6 hours* | (*c*) | — |
| Saturated steam .. .. | 212 | 1 hour | (*c*) | (*c*) | — | — | 1 hour | (*c*) | — |
| Saturated steam .. .. | 212 | 4 hours | (*c*) | (*c*) | (*c*) | (*b*)2 | 4 hours | (*c*) | (*c*) |
| Saturated steam, 90 pounds | 331 | 1 hour | (*b*)27 | (*c*) | — | — | 15 min. | (*b*)9 | — |
| Saturated steam, 90 pounds.. | 331 | 5 min. | (*b*)4 | (*c*) | (*b*)3 | (*c*) | 4 hours | (*b*)42 | — |
| Saturated steam, 30 pounds.. | 274 | — | — | — | — | — | 4 hours | (*b*)11 | (*b*)10 |
| Exhaust steam .. .. | 145 | 19 days | (*c*) | (*c*) | (*c*) | (*c*) | 22 days | (*c*) | (*c*) |
| Exhaust steam .. ..<br>Exhaust steam .. .. | 145<br>170 | — | — | — | — | — | 22 days<br>2 days | (*b*)2 | — |
| Superheated steam at atmos- .. .. | 274 | — | — | — | — | — | 4 hours | (*c*) | (*c*) |
| at atmospheric pressure .. .. | 331 | 6 hours | (*c*) | (*b*)3 | — | — | — | — | — |
| Superheated steam at 30 pounds pressure .. .. .. | 298 | — | — | — | — | — | 4 hours | (*b*)8 | — |

* Plus 26 days at 145° F.

(*a*) Denotes a gain in strength; (*b*) a loss; and (*c*) no change.

speeding up of artificial seasoning processes, is obvious, but is of limited scope, since these tests were merely static and gave no indication as to the shock-resisting powers of the treated woods. Tiemann, however, in giving an account of this research, states that the woods subjected to the high temperatures were more brittle than when naturally seasoned.

Another effect of most of the treatments recorded in the table was that the woods treated subsequently showed reduced warping and shrinkage when compared with naturally seasoned wood. An abnormal darkening of the colour of the wood was evident, especially when high temperatures were used.

Before passing away from the consideration of the effect of damp air upon wood, it may be mentioned that when the air is damp but merely warm, not only is the desiccating action low or non-existent, but the conditions favour the growth on the wood of moulds and more virulent wood-destroying fungi. And there are on record cases in which seasoning timber or the woodwork of kilns have been damaged through this cause.

## Protection of Seasoned Woods.

Seasoned or "dry" wood is hygroscopic, so that it is necessary to prevent the ingress of moisture in order to preserve the seasoned state, and to protect against the attack of fungi. Seasoned woods should be protected by coatings, applied to their surfaces, of paints, antiseptics, creosote, varnish, or other suitable materials.

Wooden parts for aircraft purposes are invariably varnished with a shellac or copal varnish, and many plywoods are also treated in this manner.

Posts which come into contact with the ground are frequently dipped in hot coal-tar or are first charred to blackness in a fire.

**Internal Protective Measures.**

Preservatives are frequently applied to the internal cells and parts of the wood, in order to increase the resistance to decay, to ward off the attacks of insects, boring worms or beetles, and of fungi. In building, marine, and railway work this system of internal protection is very widely used.

Several hundreds of different wood preserving substances have been proposed and used, and the subject of the most suitable preservatives and processes for different kinds of woods is a wide one.* The methods of injection include hydrostatic and pneumatic pressure, and imbibition or capillary action.

Amongst the more common substances that have been successfully employed may be mentioned the following—

1. TANNIN ($C_{14}H_{10}O_9$), an antiseptic substance present in the cell walls of trees, and to which the durability is due.

2. ZINC CHLORIDE† ($Zn\,Cl_2$), a cheap and effective preservative, possessing strong anti-fungi properties; it has great penetrating qualities and will impregnate timber readily. It is not suitable for marine purposes, owing to its solubility in water. The degree of dilution is about 1 part of $Zn\,Cl_2$ by volume to 50 of water, and the impregnation is carried out under a pressure of 7 or 8 atmospheres; in some cases the wood is steamed under a pressure of from 60 to 70 pounds per square inch preparatory to burnettizing, the solution consisting of 2·5 per cent. $ZnCl_2$ and 97·5 per cent. water. The total time occupied by the process varies from 5 to 10 hours. It is sometimes used with tannin (as in the Well-house process), glue being added to prevent solubility.

3. MERCURY BI-CHLORIDE ($Hg\,Cl_2$).—The Hyan process employs this salt, of which small quantities are very effective, so that the process is not costly. This salt dissolves in boiling

* See "Handbook of Wood Preservation," Amer. Wood Preservers' Assoc., 1916; "Wood and Other Organic Structural Materials," C. H. Snow (McGraw-Hill Book Co.); "The Preservation of Wood," A. J. Wallis Taylor, *Journ. Roy. Soc. Arts.*, 20th Feb., 1914.

† Or Burnettizing Process.

water, and once within the wood, resists the actual moisture of reasonably dry places much longer than copper sulphate or zinc chloride. Mercury bi-chloride attacks iron, however, and is very poisonous.

4. COPPER SULPHATE ($Cu\ SO_4$), or blue vitriol, is a valuable wood antiseptic, but it readily dissolves in water and escapes easily from the wood; it also decomposes when brought into contact with iron.

5. SUGAR.—The effect of soaking timber in saccharine or sugar solution (known as Powellizing), under the influence of heat to induce penetration, is to render the wood impermeable to fungi, to preserve it, and to increase its strength.

6. MAGNESIUM SULPHATE.—In the process known as "senilization" of wood, a solution of this salt is caused to enter the wood by means of continuous or alternating currents.

7. CREOSOTE, or products derived from water-gas tar, coal-tar, and wood by distillation. It is a powerful antiseptic and turns wood hard and dark in colour. In pines it causes toughness, but occasionally in the case of hardwoods it causes brittleness. Creosote is probably the most widely employed preservative of any. For railway ties about 6 or 8 pounds of creosote are required per cubic foot of wood treated, whilst for piles which are intended to remain under the earth or water for long periods from 12 to 24 pounds are required.

## Life of Preserved Woods.

The life of softwoods is more than doubled by the zinc chloride process, meaning a mean life of from 8 to 12 years for pine, which usually last from 2 to 5 years untreated. The actual life varies from 5 to 20 years for treated pine ties or sleepers, against 2 to 7 years for untreated ones.

Creosoting gives from 25 to 50 per cent. more life than the zinc-chloride process, but the cost of creosoting is three or four times that of the latter, and, moreover, in the case of several woods, only a superficial penetration can be effected.

It is stated that an injection of from 10 to 15 pounds of creosote oil per cubic foot gives a life of from 12 to 20 years.

The softwoods absorb (by most of the processes) nearly twice as much as the hardwoods ; for example, when mercury chloride is used the amounts used per cubic foot are: for hardwoods 3 pounds, moderately hard 6 pounds, and soft 10 pounds. In the case of creosote oil, the hardwoods, such as oak, absorb 4 to 6 pounds, and the softwoods, such as pines, 10 to 15 pounds per cubic foot, on the average. The actual amount in each case will depend upon the wood, the pressure and temperature, and nature of the process.

**Conversion Processes.**

The method whereby the chemical substances within the wood itself are converted into antiseptics is frequently employed. In the Renè process, which is one of oxidation, the wood is placed in a closed chamber, and dried by means of an air current. The air is then expelled or exhausted, and oxygen is admitted. Finally, by means of intermittent electric discharges, ozone is liberated, and the organic bodies within the wood are converted into creosotes and terpines.

In Haskin's process, the wood is placed in a closed boiler, and air at a temperature of from 300° to 500° C. is pumped in for several hours ; the pressure is then removed and the wood is allowed to cool. The organic substances are in this way converted into acetic acid, phenol, creosote, etc. It is estimated that these substances form about 12 per cent. of the weight of the wood.

## PROPERTIES OF COMMERCIAL WOODS

The mechanical and physical properties of the more important commercial timbers are dealt with at some length in Chapter VI, so that the present considerations will be confined to a brief survey of the characteristics of the majority of the timbers much used in aircraft, automobile, and mechanical engineering work.

**Ash.**

Ash grows in the temperate regions of the Northern Hemisphere; for example, in Europe and North America.

The wood resembles oak in several particulars, but is coarser, lighter, tougher, and more elastic. It is a light, brownish-white wood with yellow streaks along its length, and between each annual layer there is a ring of pores.

Ash is noted for its high tensile, shear, and compression strengths, and for its resilience. Ash trees produce good wood, whether in old or young trees, and rapid growth causes toughness.

Fig. 67.—Micrograph of Ash (*Fraxinus excelsor*) Magnified 50 Times.

The vessels in ash are small and scattered, being grouped in small arcs, and the medullary rays are invisible to the naked eye; the sapwood is invariably of a white or yellowish white colour, and the heartwood darker. Fig. 67 shows a typical micrograph of ash.

Ash logs require sawing up into planks soon after felling, otherwise cracks and shakes occur.

Ash is somewhat difficult to obtain in lengths with straight

grain, and for this reason is considered to be a wasteful timber for aeronautical purposes.

Ash bends readily when steamed or heated, the bent part being clamped into position until cold; fractures in ash are not so serious as in other timbers, owing to their length and localization.

Long lengths in ash may be readily obtained by splicing, clamping, or taping.

In the dry state ash is fairly durable, but when alternately exposed to damp influences it becomes susceptible to the attack of fungi, that is, it rots; the presence of fungi is indicated by blue or green patches.

Ash planks run from 10 to 18 feet in length, but in exceptional cases can be obtained in lengths up to 25 or 28 feet; the width usually ranges from 6 to 20 inches.

The American ashes are grouped under two heads: (*a*) White Ash, which includes the lighter coloured, more desirable wood; and (*b*) Black Ash, which includes the darker and inferior woods. American ashes includes the White, Red, Blue, Black, Green, and Oregon varieties.

**Aeronautical Ash.***

Ash for aircraft purposes should be specially selected, straight grained, as clean as possible, and free from defects. The ash usually preferred is the English variety, felled between September and January, and thoroughly wind-dried for as long a period as possible; kiln drying is allowable, but it is usual to specify the nature of the process employed.

Bent ash for aeroplane parts, such as wing tips, skids, and other articles, should be steam bent at a temperature not exceeding 220° F.

The weight of aircraft ash should be within the limits of 38 and 47 pounds per cubic foot.

It is usual to specify a bend test as follows: A beam of width 1 inch, depth 2 inches, and span 24 inches should be

* See also Specification for Ash, p. 248.

loaded* centrally, and the load increased until the beam breaks. The breaking load should not be less than 1000 pounds, and the deflection at breaking not less than $\frac{3}{4}$ inches. The minimum elastic limit shall not be less than 4500 pounds per square inch.

Ash is used for longerous, undercarriage, and fuselage struts, wing spars (built up), wing skids, undercarriage skids, tail skids, engine bearers, bent portions of wing and control surface, leading and trailing edges, etc.

In *automobile* work, ash is employed for carriage or body frame-works, spokes, felloes, handles, packing strips, and other purposes.

## Balsa Wood.

Balsa† is an exceedingly light wood grown in Central and South America. The material is composed of very thin walls which are barrel-shaped and interlace with each other; they are almost devoid of wood fibre. Balsa is somewhat similar to cork, in that its cells are filled with air, so that it possesses excellent non-conducting properties.

The specific gravity of this wood in the dry state is 0·11, a cubic foot weighing only 7·3 pounds, whilst Missouri cork-wood weight about 18 pounds per cubic foot. The bark from the cork oak (*Quercus suber*) weighs about 14 pounds per cubic foot. The ordinary commercial balsa wood always contains a certain amount of moisture, and its weight lies between 8 and 13 pounds per cubic foot.

The cellular structure of this wood is quite different from most other woods except, perhaps, basswood. The medullary or pith rays are uniformly spaced and are quite prominent in both the radial and the cross-sections. The ducts, pores, or vessels are large and remote from each other, and occur either singly or in groups in the strands between the pith rays.

* For manner of loading see p. 280.

† Fuller information is given in "The Properties of Balsa Wood," R. C. Carpenter, *Aerial Age Weekly*, 9th June, 1919.

The parts analogous to wood fibre in ordinary wood are not lignified, but are very thin walled and soft, and the ducts or pores are weakly lignified and are pitted.

The results of transverse bending tests on specimens measuring $1\frac{3}{4} \times 2\frac{1}{2} \times 20$ inches span gave a modulus of rupture of about 3000 pounds per square inch. The average modulus for a number of tests upon larger beams was about 3300 pounds per square inch.

The mean crushing or compression stress is about 2250 pounds per square inch, or about one-half that of white pine or spruce, and it was stated that very uniform results were obtained in a number of tests.

It is a very elastic material, and when the load was almost at the breaking value the loads on three of the beams were removed and the beams resumed their original shape.

Balsa is almost impossible to split, and nails can be freely driven into it without splitting it.

Balsa trees attain diameters of from 12 to 14 inches, and heights of from 40 to 60 feet.

This wood is used for buoyancy, vibration, and heat insulation purposes, and for streamline or fairing parts of aeroplanes.

## Birch.

This wood grows in Europe, Asia, and North America, and occurs in the Paper, Yellow, Sweet, and Silver varieties. Birch trees are prized for their bark, as well as for their wood; the bark containing certain oils which render it very durable and useful.

Birch is much used in the form of veneers to form plywoods for aeronautical purposes, and for tea-chests, chair bottoms, etc.; it has also been used for the laminae of aircraft propellers. Birch also figures much in furniture construction on account of its ornamental appearance; for constructional work the ordinary European birch (*betula alba*) is not very durable, and soon rots in exposed positions.

**Beech.**

This wood grows in the temperate regions of the Northern Hemisphere, and the European beech (*fagus sylvatica*) is one of the most widely used of the beeches.

Beech is a hard, heavy, strong, fine-grained wood, which somewhat resembles ash in its properties; it is not very durable, however, in exposed positions, and is liable to the attacks of insects.

It is a timber much used for wooden parts requiring hardness and non-splitting properties, such as wedges, mallets, levers, axe and hammer handles, shoe-lasts, and for wagon work, mill cogs, posts, etc.

Beech responds well to antiseptic treatment, and when impregnated with preservatives fulfils all of the requirements for building and structural purposes; in many instances it rivals oak in its properties.

**Cedar.**

The cedars include also the junipers and cypresses, but the present considerations are confined to the two principal classes of cedar, namely, the red and the white varieties.

Red cedar is a soft, light, durable, fine-grained, fragrant wood of reddish-brown colour; it includes the pencil cedars, the commonest of which, the Virginian red cedar (*Juniperus Virginiana*), is much used for making pencils, furniture, cigar boxes, and in the form of chips and shavings for protecting woollen goods from moth.

Red cedar is also used for aircraft purposes for the floats of seaplanes, and the hulls of flying and motor boats, on account of its durability in air and water.

Planks can be obtained in lengths of from 8 to 16 feet, in thicknesses up to 3 inches, and widths up to 18 inches. It is a fairly light wood, weighing from 30 to 35 pounds per cubic foot in the seasoned state.

Lebanon cedar is one of the most durable timbers, having a yellowish-brown colour, with distinct annual rings, a powerful

and characteristic odour, and slightly bitter taste. It is straight-grained, easily worked, but liable to split.

**Western Red Cedar** (*Thuja plicata*).

There are four true cedars, two in Asia and two in America. Western or giant cedar is by far the largest of these trees, and its wood is much better.

The usual height of the trees is from 100 to 150 feet, with a diameter of from 3 to 8 feet; exceptional trees attain a

FIG. 68.—CEDAR (*Cedrus libani*) × 50.

height of 200 feet, with a diameter of 15 feet. British Columbia is a noted source of this wood.

The wood is very durable and practically immune from decay. It is exceptionally light, soft, and of close, straight grain, making it easy to handle and work; moreover, it is remarkably free from warping, shrinking, and swelling. Fig. 69 shows a typical micrograph of red cedar.

The heartwood, in mature years, is generally a brownish red (occasionally a light yellow), which ages to a deeper and richer shade with an attractive silvery sheen; the sapwood, which is narrow, is white in colour. The wood has a slight

aroma, and is free from pitch; it is used for moth-proof clothes chests, closets, drawers, etc.

Western cedar is much used for cabinet-making, for the backs and sides of shelves, boxes, partitions, mouldings, etc. It is also used for exterior siding, flume construction, drains, posts, poles, canoes, row-boats, motor and flying boat hulls, trellis work, hot-house frames and sashes.

It is of interest to note that the Indians of the Pacific coast used this wood for their large war canoes, making these out

FIG. 69.—RED CEDAR (*Thuya gigantea*) × 50.

of large logs, and for their totem poles; the fibres of the inner bark were used for making rope, blankets, and thatching for their cabins.

**White Cedar.**

This wood is obtained from several arborvitaes and cypresses. It is moderately soft, whitish-yellow in colour, fine-grained, and possesses a characteristic odour; it may be employed for many aeronautical purposes in place of silver spruce, but the sources of supply are not so abundant. White cedar is rather harder than silver spruce and is very durable.

The weight of white cedar varies from 24 to 30 pounds per cubic foot. The modulus of rupture varies from 8000 to 12,000 pounds per square inch, and the modulus of elasticity from $1 \cdot 0 \times 10^6$ to $1 \cdot 7 \times 10^6$ pounds per square inch.

**Cork.**

This is a very light wood, derived from the cork oak and the cambium or bark of trees ; it weighs about 14 to 16 pounds per cubic foot. Cork is much used for lifebuoys, for heat, sound, and vibration insulating spaces, for packing pieces for aircraft instruments, floats for carburettors, cisterns, and tanks for refrigeration purposes, etc.

**Cottonwood.**

The name cottonwood includes the wood of poplar, tulip-tree, and cucumber-tree ; it is also known as whitewood, canary, and basswood.

The cottonwoods, which are mostly of American origin, are soft, rigid, fine-grained, clean, straight-grained timbers, capable of being nailed and screwed without splitting, and obtainable in fairly large sizes.

The weight of whitewood varies from 22 to 27 pounds per cubic feet.

Tulipwood is used for boxes, shelves, carvings, and domestic ware ; in aeronautical work it has been employed for ply-wood fuselage work, in the form of thin strips,* and for wing and tail plane former ribs, leading edges, and body-fairing. Poplar is also used for the same purpose. American white-wood is also much used for the centre layer of three-ply, with ash, maple, and birch for the outer layers.

Model aircraft parts for experimental and wind-channel work are frequently made of cottonwood, on account of the ease of working and the non-splitting qualities of this wood. For thin parts, however, such as model wing sections, it is not suitable, being apt to warp.

* The Deperdussin monocoque fuselage was built of tulip wood layers.

## Elm.

The elms include the English (*ulmus campestus*), mountain, rock, slippery, cork, white, and others.

Rock elm originates from America, and is noted for its clean, straight grain; boards can be obtained in lengths up to 30 or 40 feet.

Elm is a whitish, tough, fibrous, durable, strong, hard and heavy wood, which is difficult to split; it withstands shocks well and is often used for cart and carriage work, agricultural implements, cooperage, pump handles, piles, and

FIG. 70.—DOUGLAS FIR (*Pseudosuga douglasii*) × 50.

machinery. The tall, straight trunks yield pieces of timber of considerable size, and for this and other reasons elm is used in ship-building work. English elm usually possesses a twisted grain and is somewhat liable to crack.

## Fir.

The name fir includes the Douglas, silver, red, noble, and balsam varieties.

The fir imported from Norway and Sweden (*picea* or *abies excelsa*) is termed spruce fir* or white deal.

* It is not a *spruce*, however.

The Douglas fir (*pseudot suga taxifolia*) is also known under the names of Douglas spruce, Oregon pine, hard pine, Columbia pine, red fir, yellow fir, etc.

It is a durable, strong, light-red or yellow wood resembling larch ; the trees grow to very large sizes (belonging to the giant tree class), individuals having reached heights of 350 feet and diameters of from 12 to 15 feet. The annual rings vary from 4 to 40 per inch.

The deals derived from firs are widely used for building purposes, for boxes, shelves, posts, piles, etc.

Young trees of fir are used for scaffold poles, the bark being left on for protection purposes ; they may be obtained from 6 to 8 inches in diameter and 30 to 60 feet in length.

These poles are also cut down and used for making ladders.

Deal is light, elastic, tough, not difficult to work, and in the better varieties very clean and free from knots.

When Douglas fir is sawn tangentially (slash grain) the grain of the wood is shown in a beautiful figuring, and in this form is used for panelling.

The durability of Douglas fir renders it particularly suitable for wooden piping, for continuous stave and jointed conduits used in power and irrigation work, tanks, railway ties, street pavement, and other purposes. Fig. 70 shows a typical micrograph of Douglas fir.

The weight of fir varies from 30 to 36 pounds per cubic foot in the seasoned state, and the modulus of rupture from 8000 to 12,000 pounds per square inch. The modulus of elasticity varies from $1{\cdot}4$ to $1{\cdot}9 \times 10^6$.

## International Aircraft Standard Specification for Aircraft Douglas Fir.

Douglas fir has been employed for aeronautical members, such as wing spars, ribs, and struts ; the following is the I.A.S.B. specification for aircraft timber—

*2W1—Mill Specifications for Aircraft Douglas Fir.*

1. Region.—All Douglas fir timber used in the production of this material shall have grown in the North Pacific coast timber region of

Western Oregon and Washington and near-by regions of British Columbia.

2. Timber.—The trees used in the production of this lumber shall be preferably of the "young yellow fir" type, and shall be in a healthy condition at the time of felling. Brashy lumber characteristic of old, over-mature, or decadent yellow fir trees will not be accepted.

3. Logs.—The logs from which the material is produced shall be preferably "butt" logs, and in no case shall "top" logs be used.

4. Grain.—All grain shall be straight; that is, the angle of deviation from a line parallel with the edges shall not exceed 1 in 30 (1 : 30) on surfaces with diagonal grain and 1 in 20 (1 : 20) with spiral grain. Stock 4 inches and thicker may be flat grains, and stock less than 4 inches thick shall be vertical grain.

5. Texture.—(a) The wood shall be strong, tough, and elastic. Brashy pieces will not be accepted.

(b) The rate of growth of any piece shall not be less than 30 annual rings to each 3 inches (76·2 millimetres) when measured in a radial direction on either end section through the zone of maximum growth. Furthermore, no single inch (25·4 millimetres) shall have less than eight annual ring growths.

6. Knots and Burls.—(a) Not less than 90 per cent. of the total footage of each shipment shall be free from knots of all kinds, and from burly, curly, gnarly, and irregular grain, on all four sides of each piece.

(b) In the pieces comprising the balance of the shipment (10 per cent. or less) knots and burls or similar irregularities of grain or other defects will be allowed, provided the buyer is able to obtain cuttings from each piece which are clear, sound, straight-grained, and not less than 5 inches (127 millimetres) wide and 16 feet (4·88 metres) long. Not more than 25 per cent. of the total volume of each piece shall be discarded in sawing out cuttings.

7. Pitch Pockets.—(a) One pitch seam or pocket not to exceed 2 inches (50·8 millimetres) long or its equivalent in minor pockets (provided they are not in the same annual ring) will be allowed in either or both faces of each piece 16 to 31 feet (4·88 to 9·45 metres) long, and two such pockets or their equivalent in either or both faces of each piece 32 to 40 feet (9·75 to 12·19 metres) long. Pieces shorter than 16 feet (4·88 metres) and pieces narrower than 6 inches (152·4 millimetres) shall be free from pitch pockets.

(b) Pieces having pitch pockets too large or too numerous to be allowed as defined in paragraph 7 (a) will be inspected in the same manner as for knots and burls as specified in paragraph 6 (b).

8. Sap.—Bright sap will be allowed in any piece, provided it does not extend more than one-fourth the width of the piece or one-third its length.

9. Rot and Shake.—All pieces shall be free from rot, shake, dote, red heart, purple heart, and all other forms of decay.

10. Tool Marks and Other Defects.—Pieces must be free from picaroon holes, hook marks, and other defects caused by handling tools and equipment.

11. Wane.—Wane will be allowed on occasional pieces, but in no case shall it exceed either one-fourth the thickness, one-eighth the width, or one-sixth the length of the piece.

12. Dimensions.—Percentages of various thicknesses, widths, and lengths, and the respective percentages of flat and vertical grain stock to be supplied are subject to special arrangement between the purchaser and contractor at the time prices are fixed.

13. Tolerances.—(a) Thicknesses may be scant not to exceed

⅛ inch (3·18 millimetres) on occasional pieces. If more than ⅛ inch (3·18 millimetres) scant they will be accepted at contractor's option and tallied in the next inch class below.

(b) Widths may be scant not to exceed ¼ in. (6·35 mm.) on occasional pieces. If scant more than ¼ in. (6·35 millimetres) they will be accepted at contractor's option and tallied in the next inch class below.

(c) Lengths may be scant not to exceed 2 inches (50·8 millimetres) on occasional pieces. If scant more than 2 inches (50·8 millimetres), they will be accepted at contractor's option and tallied in the next 1 foot class below.

**Greenheart.**

This wood is derived from trees of the laurel family, from British Guiana, South America, and the West Indies.

The wood is hard, strong, tough, and very heavy; it has been termed the cast-iron of woods. It varies in colour from a dark greenish-brown to a chestnut colour, and is easily distinguished by the end grain, which shows minute open pores like a cane.

It is probably the strongest timber in use for compressive stresses, but is not suitable for beams as it is apt to snap suddenly; it is also liable to split and splinter, and so requires care in working.

It is very durable, due to the presence of an essential oil or alkaloid known as "biberine," which preserves it from the attacks of worms and insects; for this reason it is much used for dock work, piles, piers, jetties, marine structures, machine parts, floors, wagons, furniture, and belaying pins.

Greenheart is also occasionally used for veneers, automobile spokes, and for turnery purposes.

It weighs from 68 to 78 pounds per cubic foot, and has a modulus of rupture of about 10,000 pounds per square inch, with a modulus of elasticity of about $1{\cdot}1 \times 10^6$ lbs. per sq. in.

**Hickory.**

The hickories are derived from the temperate regions of Eastern North America and Eastern Asia, and are allied to the walnuts. The principal species number about a dozen, and include the shagbark, pignut, mocker nut, and pecan.

Hickory* is noted for its toughness and hardness, and also

* See also p. 286.

for its elasticity; it has an open-grain, and varies in colour from ivory-white (sapwood) to a dark brown.

The annual rings are clearly marked in most species, and the medullary rays are numerous but thin (shagbark).

Hickory is not a durable wood, and when impregnated is very heavy.

Hickory is chiefly used for axe and hammer handles, motor and carriage spokes and felloes, wheels, etc. It was formerly much used for aeroplane skids and struts, but is now invariably replaced by the lighter wood ash. Hickory can be obtained in boards of from 12 to 20 feet in length. The number of annual rings varies from 5 to 18.

The weight per cubic foot varies from 46 to 56 pounds in the seasoned condition. Full particulars of the bending strength properties will be found in Table XCVII on p. 286, and in several of the other tables in Chapter VI.

**Larch.**

The common larch (*Larix Europoea*) is an extremely durable timber in all situations; it is a very resinous wood, and the resin often exudes so as to form a protective varnish on the surface.

The American larches include the Tamarack and the Eastern and Western varieties.

Larch is particularly suitable for posts and sleepers, but on account of its resinous nature does not dry very readily, and so is apt to shrink and warp if cut into boards.

The wood of the common larch is of a honey-yellow colour, the hard part of the annual ring being of a reddish shade.

Larch bears driving bolts and nails better than any other resinous wood, and is therefore suitable for ship timber.

The foliage of the larch is shed every autumn, so that the trees are not truly "evergreen." The tufts of small, needle-like leaves are of a pea-green colour in the spring, and the trees are then readily distinguishable from the pines and firs.

**Mahogany** (*Mahogani swietenia.*)

The name mahogany is given to a number of tropical woods derived from Africa, Central America, and the West Indies. The most common of the mahoganies are the Honduras and the Spanish varieties, of which the former is obtained from the country of that name, and the latter from the Spanish American possessions.

The African sources are very numerous, and for this reason the qualities of the woods vary considerably.

*Honduras* mahogany is similar to cedar in colour, of somewhat straight and coarse grain, and when worked makes soft, silky shavings; it is much used for decorative timber work, such as panels, veneers, and cabinet work, on account of the beautiful polish and grain effects that can be obtained. It is used for hand-rails, doors, shop fronts, counters, and in aircraft and automobile work for instrument and dash boards, and occasionally for motor bodies.

Planks can be obtained up to 4 or 5 feet in width; cases of widths of 6 or 7 feet are on record.

The *Spanish* variety is darker, harder, and more twisted in the grain than the Honduras, with a better figure; it is much used for veneers. It can be distinguished by a white chalk-like substance in the pores, and by its red tint.

*Jarrah*,* or Australian mahogany, closely resembles the Spanish variety, but it is of rather a purer red. It is very hard, but brittle, and has been much used for paving blocks, piers, jetties, dock gates, etc., as it possesses excellent wearing qualities.

*Jarrah* can be distinguished from the similar Australian wood, *Karri*, for it has long fluted fibres, and when a splinter is burnt a white ash is left and the fibre glows afterwards; in the case of karri the ash is black and the splinter does not glow very much.

Spanish cedar is another of the mahogany species, derived

* For the properties of Australian timbers, see p. 323.

from Mexico and Cuba; the heartwood is brownish red in appearance, and is soft, fragrant, porous, and durable.

Mahogany in general is very durable and does not warp much, it is easily worked and is capable of taking a high polish.

It is used, on account of its durability in water, for the hulls of motor boats and flying boats, and for seaplane floats, usually in the form of copper-wire sewn strips upon the skeleton framework.

In aircraft work mahogany is used for instrument boards, propeller laminations, packing pieces, and veneers.

Commercially, it is used for decorative work, furniture, work, etc.

Parang mahogany is much stronger than the Honduras variety, and can be obtained in lengths of 18 feet, in widths of 10 to 16 inches, and in thicknesses up to 5 inches.

Mahogany varies in weight from 32 pounds to 45 pounds per cubic foot. The following table* gives the strength properties of some typical mahoganies—

## TABLE LXXX.

### Tests on Mahoganies.

| *Name.* | *Density, pounds per cubic inch.* | *Bending* | | *Compression* | |
|---|---|---|---|---|---|
| | | *Ultimate stress. lbs. sq. in.* | *Strength / weight.* | *Crushing stress. lbs. sq. in.* | *Strength / weight.* |
| Sekondi .. .. | ·022 | 8200 | ·62 | 5800 | ·75 |
| Grand Bassam .. | ·021 | 9600 | ·76 | 6800 | ·91 |
| Sapeli .. .. | ·026 | 5600 | ·36 | 5000 | ·55 |
| Benin .. .. | ·020 | 8500 | ·71 | 5500 | ·78 |
| Lagos .. .. | ·022 | 9500 | ·72 | 6900 | ·89 |
| Axim .. .. | ·019 | 7000 | ·62 | 5400 | ·80 |
| Khaya Senegalensis | ·019 | 9240 | ·81 | — | — |
| Bursera .. .. | ·022 | 12260 | ·93 | — | — |
| Solomon Isles .. | ·021 | 12100 | ·96 | 6250 | ·84 |
| Tabasco .. .. | ·021 | 9700 | ·77 | 6170 | ·83 |
| Honduras .. .. | ·020 | 12000 | 1·0 | 7080 | 1·0 |

* "Timber: Its Identification and Mechanical Properties," H. W. Barling, *Aeron. Journ.*, May, 1918.

The following methods have been recommended* for identifying the more important varieties of mahogany, as there has been some difficulty amongst users, and buyers, in identifying woods from different sources.

In the following table, T.S. indicates "transverse sections" and L.S. "longitudinal sections."

## MAHOGANY.

(*A*) Ring-Pored.

Each annual ring begins with a region of larger vessels producing prominent furrows in longitudinal sections. The remaining vessels are smaller and distributed.

(1) *Cedrela odorata* (Cigar-box Cedar).

The ring-pored nature of this wood is sometimes difficult to see, especially in small pieces.

Colour: Cinnamon brown.

T.S.—Medullary rays only just recognizable. Bright lines of cord parenchyma.

L.S.—Closely needle rent and lustrous. Larger furrows filled with dark red to black substance.

Soft, light, easily split, pleasant aroma.

(*B*) Scattered-Pored.—

(1) Vessels small and seldom choked.

(*a*) Light or dark cinnamon-brown to reddish-brown, darkening on exposure.

T.S.—Prominent medullary rays often slightly twisted. Fine, bright lines of cord parenchyma at almost equal intervals.

L.S.—Thickly needle rent, the furrows being often grained, lustrous, and containing a red to black filling.

Medullary rays in cross rows on tangential surface. Difficult to split.

### Mahogany (*Swietenia Mahagani*).

This includes Swietenia from Cuba, Corrinto, and Domingo. Special gravity varies with these timbers from ·56 to ·87, also the hardness.

The heaviest is probably Cuban mahogany.

In Domingo timber, the vessels very often contain a white substance.

(*b*) Light reddish, sometimes exhibiting a grey tinge.

T.S.—Annual rings visible without, in general, bright lines of cord parenchyma.

L.S.—Medullary rays not in cross rows.

### *African Mahogany.*

Under this head are a great number of timbers, most of which are named after the places from which they come. The most important, probably, are the following: Lagos, Sekondi, Benin, Grand Bassam, Axim, Sapeli, Khaya, Okume, and Gubun.

Lagos, Sekondi, Okume, and Gubun are brighter reddish, or reddish grey, with an indication of longitudinal striping due to irregular vessel and fibre growth.

Vessels in Lagos and Sekondi generally filled with dark-red to black substance.

Vessels in Gubun and Okume usually not filled.

* E. J. H. Lynam, *Aero. Journ.*, May, 1918.

(*C*) Light Ochre to Golden Yellow.
T.S.—Prominent annual rings.
L.S.—Lustrous, with wavy, irregular, and usually unfilled furrows.
Light, soft, and easily split.

## Maples.

These include the European varieties, sycamore, hard or sugar maple (North America), silver, red, and Oregon maples.

Maple has a uniform yellowish colour, is of fine compact structure, and is noted for its good appearance.

The *bird's-eye* and *curly* maples are particularly valuable for veneers, musical instruments, tobacco pipes, cabinets, and furniture.

Maple is noted for its durability and wearing properties; it is used for flooring, blocks, etc.

Maple is also used for the base of large printing type, piano-actions, shoe-lasts, pegs, ship keels, vehicles, and other similar purposes.

Maple plywood with a cotton-wood central layer has been much used, both commercially and for aircraft work.

## Oak.

The oaks, which comprise a large variety, grow in the Northern Hemisphere, and at high altitudes just south of the equator. There are three principal varieties grown in England, namely—

(*a*) The *Old English*, or stalk-fruited (*Quercus sobur*).

(*b*) The *Bay*, or cluster-fruited (*Quercus sessiliflora*).

(*c*) The *Durmast* (*Quercus pubescens*).

The timber from the stalk-fruited oak is considered to be superior to that of the others; it is lighter in colour, has a straight grain free from knots, and has numerous distinctly marked medullary rays, so that it shows a good silver grain. Fig. 71 shows a typical micrograph of oak. It is easier to work and less liable to warp than the bay oak.

*American* or *Quebec Oak* (*Quercus alba*), which is sometimes known as white oak from the colour of the bark, has a pale reddish-brown colour, with a straighter and coarser grain

than the English oak; the sapwood is lighter than the heartwood. It is very sound, hard, and tough, and bends easily when steamed. This variety is used in shipbuilding, cooperage, railway ties, cabinet-making, furniture, wheels, agricultural implements, etc.

The bark of white oak is rich in tannin, and is used in the tanning of leather

*Dantzic Oak* is of a dark-brown colour, with a straight grain which is close and compact, bright medullary rays,

FIG. 71.—OAK (*Quercus*) × 50.

free from knots, resilient, moderately durable, and easily bent when steamed.

*Riga Oak* resembles the Dantzic variety but has more numerous and more distinct medullary rays; it is imported in half round logs.

Oak, in general, has narrow sapwood, lighter than the heartwood in colour, the medullary rays being very marked, giving the wood a silky grain (due to the white parenchyma inside). It has no resin ducts, and the annual rings which have dark borders, vary from about 5 to 8 per inch. The air vessels are seen as hollow streaks in longitudinal section, and as small circular bulges in transverse section.

Oak is apt to split and check in drying.

Although it is very strong, it is not so flexible nor as strong for its weight as ash, so that it is seldom used for aircraft work.

Oak is tough and durable in contact with the ground; it contains gallic acid, however, which attacks iron fittings, but the scale formed prevents the darkened wood from further injury. Copper or copper alloy fittings are more suitable for oak parts.

The weight of seasoned oak varies from 43 pounds to 56 pounds per cubic foot.

### Poplar.

See Cottonwood.

### Pines.

These coniferous woods are probably more widely used for carpentry and building purposes than any others; they grow in many parts of Europe and America, and about thirty-six of the known species grow in the latter country.

Pine trees are characterized by their long straight trunks, which, when grown in forests, are usually devoid of branches for some distance up the trunks.

Pines are divided into two classes, namely, the *soft* and the *hard* pines.

The soft pines have soft, light, rather weak, clean, uniform wood which is fairly free from resin and knots, and can be easily worked; the annual layers are not so well defined as in the case of the hard pines. The presence of resin ducts is also a feature of this class.

Soft pines include the white, pattern-makers', or spruce pine, and the sugar pine.

The American white pine (*pinus strobus*), known in Europe as the yellow pine, is widely employed for building and structural purposes; it is characterized by its cream white-coloured heartwood, with nearly white sapwood; its close, straight grain and compact structure. White pine can be

recognized by the short hair-like marks or black dashes in the grain.

The wood is soft and uniform, easy to nail, and receives paint well; it shrinks, swells, and warps less than the other pines.

White pine is largely used for pattern-making, on account of the ease with which it can be worked and its durable nature. It has a weight of about 22 to 26 pounds per cubic foot in the seasoned state, and a modulus of rupture of about 7900 to 8900 pounds per square inch.

White pine is used for carpentry, matches, spars, boxes, and other purposes.

The *hard* pines are harder, stronger, heavier, more resinous, of a deeper colour, and more difficult to work than the soft pines. The annual rings are more pronounced, and the trees in general are larger.

The American varieties include the longleaf, shortleaf, Cuban, and loblolly pines; other pines of the hard variety are the Memel, Quebec, Norway, pitch, and Scots (*pinus sylvestus*), or Dantzic.

The properties of the commercial American hard pines are fully dealt with in Chapter VI.

The *Longleaf Pine* is the principal tree of the hard pine group, and the wood is obtainable in very large-sized pieces, being much used for docks, trestles, stages, piles, and other purposes. The trees yield turpentine, tar, and resin; the trees are usually tapped for these products a few times before felling.

*Cuban Pine* resembles longleaf pine in many of its properties and is noted for its yields of pitch and turpentine.

From *Scots Pine*, which is also known as Dantzic or Northern pine and Scotch fir, originates much of the timber known as red and yellow "deal"; the heartwood varies in colour from reddish to yellowish white, and the sapwood is similar. The wood, which is light, hard, tough, and elastic, is widely used in carpentry, for building construction, beams, masts,

and heavy timber. The name *deal* also signifies the sizes of the boards, namely, 9 inches wide, *planks* being 11 inches, wide, *battens* 7 inches wide, and *narrow battens* 4½ inches wide.

Scots pine is, as a rule, straight grained and free from knots, and is usually known, in Europe, by the name of the port from which it is shipped; for example, Christiania, Archangel, Memel, etc. Fig. 72 shows a typical micrograph of Scots pine.

In aeronautical work, the softer pines have been employed for packing pieces, former ribs, fairings, stringers, and similar

FIG. 72.—SCOTS PINE (*penus silvestris*) × 50.

purposes; in a few cases, red pine has been used for solid and built up wing spars, and struts.

The *Kauri Pine*, or New Zealand pine (*dammara Australis*), is a coniferous tree originating from New Zealand. It grows to a height of 80 to 140 feet, with a clean straight stem 4 to 8 feet in diameter.

The wood is strong, light, close, even, and fine grained, the colour being of a light yellowish-brown, or full honey-yellow, with a silky lustre; the annual rings are only faintly marked. This wood somewhat resembles satinwood in appearance, and the "mottled Kauri" is much used for decorative work, panels, cabinets, etc.

Kauri glues well, but is apt to split in nailing. It is used in England chiefly for brass-casting pattern work. The wood seasons well, works readily, and receives a high polish; it wears evenly and has an agreeable odour. The tree itself is a source of much of the resin used in high grade varnishes; the resin unites easily with linseed oil, and makes one of the best oil varnishes known.

The weight of seasoned Kauri* is about 33 pounds per cubic foot.

**Silver Spruce.**

Although the spruces are somewhat numerous, including the Norway spruce, or white fir, white, red, Engelmann, Western Douglas, Western spruces, and others, it is here only proposed to describe the variety which is very widely used in aircraft constructional work, namely, the *Sitka* or *Silver Spruce* (*picea sitchensis*).

Most of the silver spruce used in aeronautical work is derived from North America, notably the Pacific Coast region, or British Columbia.†

Mature trees average 150 feet in height and 4 feet in diameter, while some trees grow to over 200 feet, and 10 to 15 feet in diameter. The tall, straight boles, with their moderate taper, furnish saw timber of the best quality, and in largest dimensions, unusually clear and free from defects.

The wood varies in colour from white to a white tinged with very light brown, is soft and light (weighing about 24 to 28 pounds per cubic foot), but tough and very strong for its weight.

For aeronautical purposes it is probably one of the strongest materials, for its weight, in use. It is even grained, long fibred, easily worked, non-resinous, odourless, tasteless, flexible, and resonant. Figs. 73 and 74 show the micro-structure of silver spruce.

* Laslett.

† See "British Columbia Timber," issued by the British Columbia Government, Victoria, B.C.

It does not warp or split readily, and makes excellent core stock for veneered articles, drawer bottoms, and panels. Its strength, lightness of weight, lack of taste and odour render it very useful for box and cooperage work, and for storing foodstuffs.

**Aeronautical Spruce.**

For aeronautical work the logs should be rift sawn, and should have edge grain. The number of annual rings per inch should be between 8 and 15.

FIG. 73.—SPRUCE (*Picea excelsea*) × 50.

Spruce of very rapid growth is inferior to that of slower growth, and the number of annual rings per inch should not be greater than 15 nor less than about 8.

Contrary to the usual case with timber, spruce does not show any difference in quality with height in the tree, but the quality varies with the location in the cross-section of the tree.

Wood immediately surrounding the pith centre is generally weak and light, and it increases in density and strength away from the centre. The increase in density is not so marked as the increase in strength.

In trees above medium size neither density nor strength increase with diameter.

The modulus of rupture of spruce, in pounds per square inch $= 25000 \sqrt{G^2}$, and the maximum crushing strength, in pounds per square inch $= 12000 \sqrt{G^2}$, where G is the specific gravity based upon the green volume.

FIG. 74.—SILVER SPRUCE MICROGRAPH.

As an example of the effect of drying on strength, a piece of clear green wood having a modulus of rupture of 4500 pounds per square inch, and a maximum crushing strength of 2000 pounds per square inch along the grain, gave, upon drying to the condition of aeroplane stock, the corresponding values of 8000 and 4000 pounds per square inch respectively.

The timber should preferably have been air-seasoned for a few months before kiln-drying.

It is usual to specify a bending test as follows: A beam

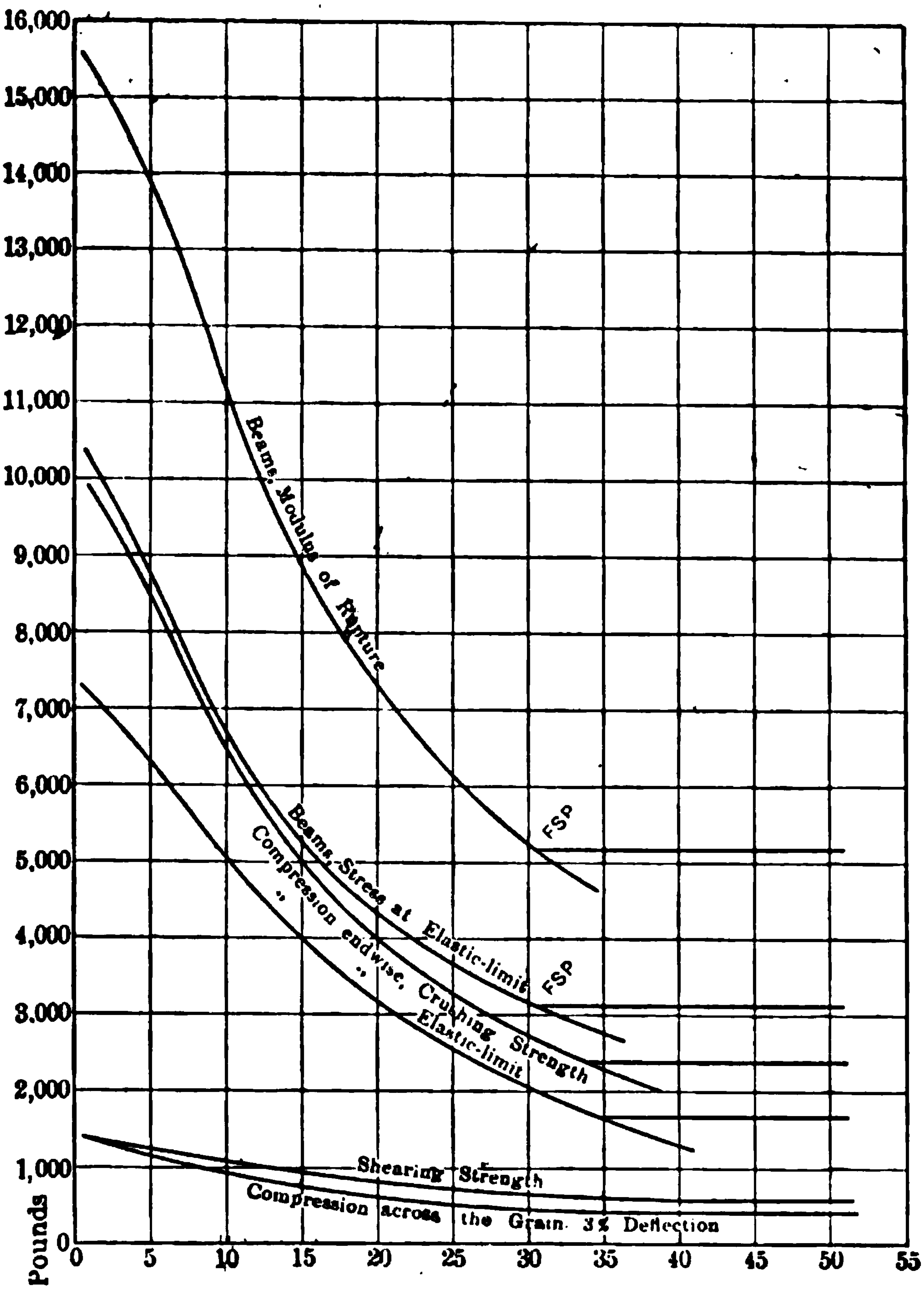



FIG. 75.—MECHANICAL PROPERTIES OF SILVER SPRUCE, FOR DIFFERENT MOISTURE CONTENTS (*Abscissae*).

24 inches long by 2 inches deep by 1 inch wide should be supported at its ends and loaded at the centre. The minimum breaking load should not be less than 950 pounds, and the deflection at the breaking load not less than 1 inch. The

minimum value of the elastic limit (in bending) should exceed 4500 pounds per square inch.

Silver spruce can be obtained commercially in boards varying from 10 to 32 feet in length, from 9 to 24 inches wide, and from 3 to 6 inches thick.

When silver spruce is dried, it shrinks about 12½ per cent. in volume from the green to the oven-dry condition, but the actual shrinkage in any particular case will depend partly upon the specific gravity in the green condition. Fig. 76* shows the relation between the volumetric shrinkage and the specific gravity of different spruces. About 0·6 of the shrinkage is tangential, and the rest radial.

The ultimate moisture in aircraft silver spruce is about 9 or 10 per cent., and each change of 1 per cent. moisture at this standard may be assumed to give about $\frac{1}{20}$ of the total shrinkage.

The diagram shows that spruce tends to show a greater shrinkage in heavier than in light pieces.

Fig. 75† shows the relation between the moisture content and the various mechanical strength properties of spruce; the letters F S P denote the fibre-saturation point.

Table LXXXI* gives some bending tests results upon aircraft spruce; other values of the strength properties are given in Chapter VI, and in Table LXXXII.

## SPRUCE.

Tests on specimens cut from four balks of selected timber.

Moisture: Somewhat greater than 10 per cent.

Average density: ·016 pound per cubic inch; 150 tests, fluctuation ± 20 per cent.

* "The Use of Spruce in Aeroplane Construction," J. A. Newlin, *Aerial Age Weekly*, 1st April, 1918.

† "The Mechanical Properties of Wood," S. J. Record. (J. Waley & Sons.)

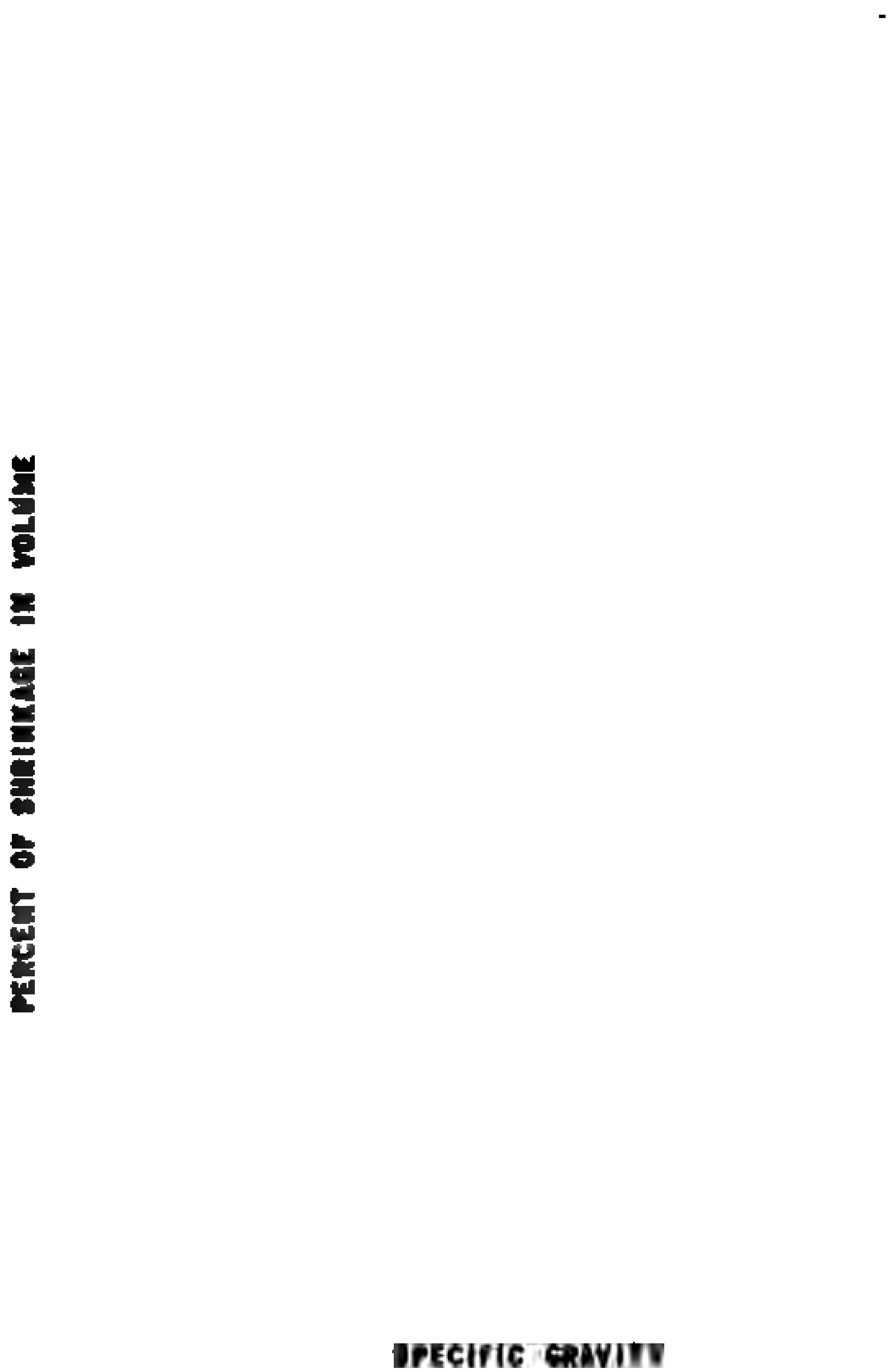

PERCENT OF SHRINKAGE IN VOLUME
SPECIFIC GRAVITY
BASED ON OVEN DRY VOLUME

Fig. 76.

TABLE LXXXI.

PURE BENDING TESTS.

| | | *Average pounds per sq. inch.* | *No. of Tests.* | *Fluctuation.* |
|---|---|---|---|---|
| Beam parallel to grain. | Elastic limit stress .. | 6200 | 70 | ±25% |
| | Ultimate stress .. | 12500 | 40 | ±10% |
| | Young's modulus, $E$ | $1{\cdot}9 \times 10^6$ | 100 | ±20% |
| Beam parallel to radius | Elastic limit stress .. | 300 | 50 | ±50% |
| | Ultimate stress .. | 1000 | 50 | ±30% |
| | Young's modulus, $E$ | $\cdot 11 \times 10^6$ | 50 | ±10% |

TORSION TEST.

| | | *Average pounds per sq. inch.* | *No. of tests.* | *Fluctuation.* |
|---|---|---|---|---|
| Torsion about axis parallel to grain | Torsion modulus, $N$ .. | $\cdot 08 \times 10^6$ | 4 | ±10% |

The above figures have been reduced to the average density of 0·016 pound per cubic inch on the assumption that the stresses and elastic constants are proportional to density.

Spruce is used in aeroplane construction work probably more widely than any other material, on account of its great strength-weight ratio ; it has replaced ash in many instances. In particular it is much used for wing spars, longerons, inter-plane inter-spar fuselage and undercarriage struts, former and main-ribs, streamlined fairings for tubes and wires, light propellers, leading and trailing edges, etc. It should not, however, be employed in cases where great localization of load occurs, owing to its low shearing strength ; for this reason ash or ply is preferable for engine bearers, etc. Spruce has a somewhat " gritty " grain, and wood-workers find that their edge tools require sharpening rather more frequently than in the case of similar woods.

## International Aircraft Standard Specification.

### *Mill Specifications for Aircraft Spruce.*

1. Timber.—The following species of spruce may be used in aircraft construction : Sitka spruce (*Picca sitkensis*), red spruce (*Picca rubens*), white spruce (*Picca canadensis*). The trees from which the logs are cut shall be in a healthy condition at the time of felling.

2. Logs.—The logs from which the lumber is produced shall be freshly cut. No logs shall be used which have been allowed to stain or decay.

3. Grain.—The grain shall be straight ; that is, the angle of deviation from a line parallel to the edges shall not exceed 1 in 30 (1 : 30) on surfaces with the diagonal grain and 1 in 20 (1 : 20) on surfaces with spiral grain. Stock 4 inches and thicker may be flat grain ; stock less than 4 inches thick shall be vertical grain.

4. Texture.—(*a*) The wood shall be strong, tough, and elastic. Brashy pieces will not be accepted.

(*b*) The rate of growth of any piece shall not be less than 18 annual rings to each 3 inches (76·2 millimetres) (an average of 6 rings to the inch, 25·4 millimetres) when measured in a radial direction through the zone of maximum growth on either end section. Furthermore, no single inch (25·4 millimetres) shall have less than 4 annual growth rings and not more than 10 per cent. of the stock shall contain less than 8 rings per inch (25·4 millimetres).

5. Knots and Burls.—(*a*) At least 75 per cent. of the total footage of each shipment shall be free from knots and from burly, curly, gnarly, and irregular grain on all four sides of each piece.

(*b*) In the pieces comprising the balance of the shipment (25 per cent. or less) knots and burls, or small irregularities of grain and other defects will be allowed, provided that the buyer is able to obtain from each piece clear, sound, straight-grained cuttings over 10 feet (5·05 metres) in length and not less than 4 inches (101·6 millimetres) wide, by sawing out and discarding not more than 25 per cent. of the total volume of the piece.

6. Pitch Pockets.—(*a*) One pitch seam or pocket less than 2 inches (50·8 millimetres) long, or its equivalent in minor pockets (provided they are not in the same annual ring), will be allowed on any face or on any two opposite faces of each piece 16 to 31 feet (4·88 to 9·45 metres) long. Two pockets or their equivalent on any face or on any two opposite faces of each piece over 32 feet (9·75 metres) long. Pieces shorter than 16 feet (4·88 metres) and pieces narrower than 6 inches (152·4 millimetres) shall be free from pitch pockets.

(*b*) When the number and size of pitch pockets exceed the limits stated in paragraph 6 (*a*) the provisions of paragraph 5 (*a*) shall govern.

7. Sap.—Bright sap shall not constitute more than one-fourth the width of a piece nor more than one-third of its length.

8. Rot and Shake.—All pieces shall be free from shake, rot, dote, and all other forms of decay.

9. Tool Marks and Other Defects.—Pieces must be free from picaroon holes, hook marks, and other defects caused by handling tools and equipment.

10. Wane.—Wane will be allowed on occasional pieces, but in no case shall it exceed either one-fourth the thickness, one-eighth the width, or one-sixth the length of the piece.

11. Dimensions.—Percentages of various thicknesses, widths, and lengths, and the respective percentages of flat and vertical grain stock to be supplied are subject to special arrangement between purchaser and contractor at the time prices are fixed.

12. TOLERANCES.—(*a*) Thicknesses may be scant, not to exceed ⅛ inch (3·18 millimetres) on occasional pieces. If more than ⅛ inch (3·18 millimetres) scant, they will be accepted at seller's option and tallied in the next inch class below.

(*b*) Widths may be scant not to exceed ¼ inch (6·35 millimetres) on occasional pieces. If scant more than ¼ inch (6·35 millimetres) they will be accepted at seller's option and tallied in the next inch class below.

(*c*) Lengths may be scant not to exceed 2 inches (50·8 millimetres) on occasional pieces. If scant more than 2 inches (50·8 millimetres), they will be accepted at seller's option and tallied in the next 1 foot class below.

**Teak** (*Tectona grandis*).

This is a valuable wood for permanent work, as it contains an essential oil that preserves it from the attacks of insects and renders it very durable. It is of a yellowish or greenish-brown colour when freshly worked, but darkens to a deep brown with age; it has a straight and open grain, and possesses a strong odour.

Teak grows in India, Burma, Malay Peninsula, Sumatra, Java, and Ceylon, and is known as the "Oak of the Indian Forests." The wood is fairly hard and heavy, weighing from 47 to 53 pounds per cubic foot.

Teak bleaches almost to an oak colour when exposed to the weather, but retains its brown colour when varnished; it withstands the action of temperature changes and of moisture exceedingly well.

Teak is much used for building purposes, railway carriages, carvings, furniture, and as a backing for armour plate. It is an excellent wood for ship-building purposes, and for ship fittings, deck-houses, etc.

**Walnut** (*Juglans.*)

The principal commercial walnuts are the English or royal walnut, French walnut, and the American or black walnut.

Circassian walnut is the name usually applied to the wood of European walnut, which is almost exclusively used for costly decorations, piano cases, gunstocks, and high grade furniture. French walnut has been much used for aircraft propellers on account of its durability, strength, and non-warping qualities.

The American walnut (*juglans cinerea*) and butternut or white walnut are now chiefly used for aircraft propeller work, cabinets, and furniture.

The black variety possesses a rich, dark, chocolate-brown heartwood, the sapwood being thin and lighter in colour; it is rather coarse grained. Fig. 77 shows the micro-structure of black walnut (*juglans nigra*).

The weight varies from 37 to 42 pounds per cubic foot in the seasoned state, and the modulus of rupture is about 12,000 pounds per square inch.

FIG. 77.—WALNUT (*Juglans nigra*) × 50.

This timber is imported in lengths of from 8 to 16 feet, in widths of 6 to 15 inches, and in thickness ranging from ½ inch upwards; for propeller work the straight grained varieties only are used.

It is usual, for aircraft propeller material, to specify a bend test as follows: A beam 24 inches long by 2 inches deep by 1 inch wide supported at its ends and loaded centrally should not break with a smaller load than 1250 pounds, and the minimum deflection just before breaking should not be less than ¾ inch. The minimum value of the elastic limit (bending) should not be less than 4500 pounds per square inch.

The weight of propeller walnut should be within the limits of 35 and 45 pounds per cubic foot.

Walnut for propeller work should be first air-seasoned for several months, and then, if required, should be kiln-dried, the temperature not exceeding about 140° F.

It is usual to cut the timber to the correct thicknesses for the laminations, namely, from ½ inch to ¾ inch, and to stack the boards in the propeller shops, which should be kept at a temperature of about 80° F., with a relative humidity of about 45 to 55 per cent., until they are required for use.

## TABLE LXXXII.

### Properties of Aircraft Timbers.*

| *Property.* | *Spruce, Sitka, Red, White (Picea Rubens).* | *Western Yellow, or Calif. White Pine (Pinus Ponderoso)* | *Pine, Sugar (Pinus Lambertiana).* | *Douglas Fir.* |
|---|---|---|---|---|
| *Specific Gravity* based on volume and weight when oven-dry— | | | | |
| Average .. .. .. | ·41 | ·42 | ·39 | ·52 |
| Minimum .. .. .. | ·36 | ·38 | ·36 | ·47 |
| *Weight* at 15 per cent. moisture. Pounds per cubic foot .. .. | 27 | 28 | 27 | 34 |
| *Shrinkage* from green to oven-dry condition. Per cent.— | | | | |
| Radial .. .. .. | 3·9 | 3·9 | 2·9 | 5·0 |
| Tangential .. .. .. | 7·5 | 6·4 | 5·6 | 7·9 |
| *Static Bending.* Fibre stress at elastic limit. Pounds per square inch .. | 5100 | 6800 | 5300 | 6800 |
| *Modulus of Rupture.* Pounds per square inch .. .. .. | 7900 | 8700 | 7400 | 9700 |
| *Modulus of Elasticity.* Pounds per square inch .. .. .. | $1·3 \times 10^6$ | $1·3 \times 10^6$ | $1·1 \times 10$ | $1·78 \times 10^6$ |
| *Work to Maximum Load.* Inch-pounds per cubic inch .. .. | 7·4 | 6·7 | 5·0 | 7·2 |
| *Compression* parallel to grain. Maximum crushing strength. Pounds per square inch .. .. | 4300 | 5000 | 4300 | 6000 |
| *Compression* perpendicular to grain. Fibre stress at elastic limit. Pounds per square inch .. .. .. | 500 | 640 | 540 | 750 |
| *Shearing Strength* parallel to grain. Pounds per square inch .. .. | 920 | 1040 | 950 | 1020 |
| *Hardness,* side. Load required to imbed 0·444 inch ball to one-half its diameter. Pounds .. .. | 430 | 430 | 410 | 580 |

* Forest Products Laboratory. Madison, Wisconsin. Also see *Aviation* April, 1918.

## British Standard Specification* for Aircraft Material. (Extract.)

### *Ash.*

1. Quality.—The timber shall be butt lengths of ash (*Fraxinus excelsior*, L.) of European growth. It shall not have more than 16 rings per inch, except in the case of approved small trees.

(*Note*.—Wide ringed ash is preferable to narrow ringed material. Timber having more than 16 rings per inch may be accepted, provided that its toughness and strength have been found satisfactory by mechanical tests. Small trees, well-grown, having more than 16 rings per inch, frequently provide satisfactory material. The timber should preferably be felled between the months of November and March.)

2. Weight per Cubic Foot.—The weight per cubic foot of the timber shall be not less than 38 pounds when the moisture content is 15 per cent.

3. Seasoning.—(*a*) *For ordinary use*. The timber shall be naturally seasoned if possible. If kiln-dried timber is used the following conditions shall be complied with—

(i) The timber shall be dried in an approved kiln.
(ii) Autograph records shall be kept showing the temperature and humidity conditions during the process.
(iii) The maximum temperature shall not exceed 125° F.
(iv) The moisture content at the conclusion of the process shall be as follows—

| | | | |
|---|---|---|---|
| Summer (Mid. April to Mid. Oct.) | not more than 20 per cent. and | | |
| | not less than | 15 | ,, |
| Winter (Mid. Oct. to Mid. April) | not more than | 18 | ,, and |
| | not less than | 14 | ,, |

(*b*) *For Steam Bending*.—Timber which is to be subjected to straightening or bending by steam treatment shall preferably not be seasoned, and shall not be kiln-dried.

4. Dryness of Timber.—(*a*) *Seasoned Timber*. The timber shall not be reduced to its final shape and size until the moisture has been reduced to 16 per cent. or less.

(*b*) *Unseasoned Timber for Bending*.—Timber that is to be subjected to straightening or bending by steam treatment shall contain at least 25 per cent. of moisture, which should preferably be the original sap moisture.

(*Note*.—The process of steaming and subsequent drying takes the place of artificial seasoning.)

5. Dryness Tests.—(*a*) *Selection of Test Pieces*. Samples shall be cut from the timber, whether unseasoned or seasoned, and shall be tested for moisture content.

6. Conversion.—Parts cut from planks should, as far as possible, be cut following the grain, and may subsequently be straightened by steam treatment. Planks in which the grain is too curved to allow of straightening should not be rejected. Irregular and curved parts should, as far as possible, be obtained from such timber with naturally

* British Engineering Standards Association, 1918.

curved grain, so that the grain of the wood is continuous throughout the length of the part.

7. Straightness of Grain.—The maximum inclination of the grain to the length of the part shall not exceed one in ten.

8. Freedom from Defects.—The timber shall contain no deleterious knots or shakes, it shall not contain curls, burrs, rammy figure, caney grain, signs of prolonged weathering, black heart, foxiness, or other forms of rot. At least half of each annual ring shall consist of autumn grown wood of close texture.

(*Note.*—Material containing abnormally large and open pores, or pores filled with brilliant yellow powdery secretion may be expected to be brittle. As a rule, the lighter coloured material is the better quality.)

9. Mechanical Tests.—(*a*) *Compression Tests.* A test piece 1 inch by 1 inch by 2 inches long shall give an ultimate strength not less than the value shown in the following table, depending on the moisture in the test piece—

| *Percentage moisture content of sample.* | *Minimum ultimate strength.* |
|---|---|
| | *Pounds per sq. inch.* |
| 13 | 5600 |
| 14 | 5300 |
| 15 | 5000 |
| 16 | 4700 |
| 17 | 4400 |

(*b*) *Notched Bar Tests for Brittleness.* A standard test piece, when tested in an impact testing machine shall not absorb less than 10 foot-pounds. The sides of the test piece shall be cut radially and tangentially, and the blow shall be applied in the tangential direction.

(*Note.*—Where a suitable machine is not available the test piece shall be broken by a blow with a hammer. The fracture shall show a satisfactory amount of fibrous splinter.)

10. Bending Test.—*Selection of Test Piece.* A lath of the material, ¼ inch thick, shall withstand the following test—

The lath shall be bent round a semicircle of 1½ feet in diameter without showing signs of fracture.

11. Steam Bending.—(*a*) *Temperature of Steam.* During steam treatment the maximum temperature of the steam shall not exceed 220° F. (2 pounds per square inch), and the timber shall remain in the steam no longer than is necessary to secure the necessary degree of pliability.

(*b*) *Curvature.*—The timber shall not be bent to a curve of less radius than 12 times its radial width, or straightened from a curve of less radius than 40 times its radial width.

Curved pieces of smaller radius are undesirable, but, if necessary, such pieces shall be produced of laminated timber or by bending the timber in a master strap clamp.

## British Standard Specification* for Aircraft Material.

### *Mahogany (Central American).*

1. Quality.—The timber shall be mahogany (*Swietenia mahagoni*, Jacq, and *Swietenia macrophylla*, King).

2. Weight per Cubic Foot.—The weight per cubic foot of the timber shall be not less than 34 pounds when the moisture content is 15 per cent.

3. Seasoning.—The timber shall be naturally seasoned if possible. If kiln-dried timber is used the following conditions shall be complied with—

(i) The timber shall be dried in an approved kiln.
(ii) Autographic records shall be kept showing the temperature and humidity conditions during the process.
(iii) The maximum temperature shall not exceed 125° F.
(iv) The moisture content at the conclusion of the process shall be as follows—

| | | | | |
|---|---|---|---|---|
| Summer (Mid. April to Mid. Oct.) | not more than | 16 | per cent. | and |
| | not less than | 12 | ,, | |
| Winter (Mid. Oct. to Mid. April) | not more than | 14 | ,, | and |
| | not less than | 10 | ,, | |

4. Dryness of Timber.—*Seasoned Timber.* The timber shall not be reduced to its final shape and size until the moisture has been reduced to 14 per cent. or less, nor shall any parts of the wood be glued together until this degree of dryness is attained.

5. Dryness Tests.—*Selection of Test Pieces.* Samples shall be cut by the contractor from the timber, whether unseasoned or seasoned, and shall be tested for moisture content.

6. Freedom from Defects.—The wood in the finished parts shall contain no deleterious wormholes, sapwood, gum veins, spongy heart, or other forms of rot, knots, shakes, cross shake, fiddle-back figure, roe figure, and other forms of cross and curly grain.

7. Mechanical Tests.—(*a*) *Selection of Test Pieces.* Samples shall be cut by the contractor from the seasoned timber and a number of test pieces shall be prepared from these samples for the following tests.

(*b*) *Notched Bar Tests for Brittleness.*—A standard test piece, when tested in an impact testing machine, shall not absorb less than 6 foot-pounds. The sides of the test piece shall be cut radially and tangentially and the blow shall be applied in the tangential direction.

(*Note.*—Where a suitable machine is not available, the test piece shall be broken by a blow with a hammer. The fracture shall show a satisfactory fibrous splinter.)

(*c*) *Bending Test for Modulus of Rupture.*—A test piece cut parallel to the grain, having a square section of 1 inch by 1 inch, when tested shall give the following result—

Modulus of rupture .. Not less than 11,000 pounds per sq. inch.

* British Engineering Standards Association, 1918

## British Standard Specification* for Aircraft Material.

### *Mahogany (West African).*

1. Quality.—The timber shall be mahogany (*Khaya sp.*) having the same general characteristics as first quality mahogany imported from Grand Bassam or Benin.

2. Weight per Cubic Foot.—The weight per cubic foot of the timber shall not be less than 34 pounds, when the moisture content is 15 per cent.

3. Seasoning.—The timber shall be naturally seasoned if possible. If kiln-dried timber is used the following conditions shall be complied with—

(i) The timber shall be dried in an approved kiln.
(ii) Autographic records shall be kept showing the temperature and humidity conditions during the process.
(iii) The maximum temperature shall not exceed 125° F.
(iv) The moisture content at the conclusion of the process shall be as follows—

| | | | | |
|---|---|---|---|---|
| Summer (Mid. April to Mid. Oct.) | not more than | 16 | per cent. | and |
| | not less than | 12 | ,, | |
| Winter (Mid. Oct. to Mid. April) | not more than | 14 | ,, | and |
| | not less than | 10 | ,, | |

4. Dryness of Timber.—The timber shall not be reduced to its final shape and size until the moisture has been reduced to 14 per cent. or less, nor shall any parts of the wood be glued together until this degree of dryness is attained.

5. Dryness Tests.—*Selection of Test Pieces.* Samples shall be cut by the contractor from the timber, whether seasoned or unseasoned, and shall be tested for moisture content as and when required.

6. Freedom from Defects.—The wood in the finished parts shall contain no deleterious wormholes, sapwood, gum veins, spongy heart, or other forms of rot, knots, shakes, cross shake, fiddle-back figure, roe figure, and other forms of cross and curly grain.

7. Mechanical Tests.—(*a*) *Selection of Test Pieces.*—Samples shall be cut by the contractor from the seasoned timber, and a number of test pieces shall be prepared from these samples for the following tests.

(*b*) *Notched Bar Tests for Brittleness.*—A standard test piece, when tested in an impact testing machine, shall not absorb less than 6 foot-pounds. The sides of the test piece shall be cut radially and tangentially and the blow shall be applied in the tangential direction.

(*Note.*—Where a suitable machine is not available, the test piece shall be broken by a blow with a hammer. The fracture shall show a satisfactory fibrous splinter.)

(*c*) *Bending Test for Modulus of Rupture.*—A test piece cut parallel to the grain, having a square section 1 inch by 1 inch, when tested shall give the following results—

Modulus of rupture .. Not less than 11,000 pounds per sq. inch.

* British Engineering Standards Association, 1918.

## Air Ministry Specification for Silver Spruce and Approved Substitutes.

1. Quality.—(*a*) The timber is to be the first quality of any of the following woods, viz.: Silver spruce (*Picea sitchensis*, Carr.), Quebec spruce (*Picea alba* and *Picea nigra*, Link), White Sea white deal (*Picea excelsa*, Link), White Sea red deal (*Pinus sylvestris*, L.), West Virginia spruce (*Picea rubeus*, Sargeant), and North Carolina spruce, when this is the same wood as West Virginia spruce, but grown in North Carolina, Port Orford cedar (*Chamaecyparis Lawsoniana*, Murr.), New Zealand kauri (*Agathis* [*Dammara*] *Australis*, Salisb.), Canadian white pine (*Pinus Strobus*, L.), Oregon pine (*Pseudotsuga Douglasii*, Carr.).

(*b*) It should be butt lengths, slow grown (not less than 6 annual rings per inch), and preferably rift-sawn.

(*c*) *Grades.*—All approved timbers complying with Grade A tests are to be classed as Grade A.

All approved timbers complying with Grade B tests are to be classed as Grade B.

2. Freedom from Defects.—The timber is to be clean, straight-grained, free from dote, deleterious shakes, knots, and resin pockets. It is to be cut parallel to the grain (as determined by the Splitting Test specified in Clause 5).

3. Seasoning.—The timber is to be thoroughly seasoned naturally, if possible; but, if not, may be conditioned after cutting into overhead sizes. The conditioning is to be carried out in a well-ventilated place at a temperature not exceeding 85° F. The moisture at the end of the process is to be between 14 and 17 per cent., calculated on the weight of the dry wood. An autographic record is to be kept, showing the temperature and humidity during the process.

4. Weight.—The weight is not to be less than 25 pounds per cubic foot when it contains 15 per cent. of moisture.

5. Mechanical Tests.—(*a*) The timber is to comply with the following tests—

(*b*) *Compression Test.*—Standard test pieces turned parallel to the grain (or alternatively cut 1 inch square and between 2 and 3 inches long), when tested in compression, must give an ultimate strength not less than—

| | | | |
|---|---|---|---|
| Ultimate strength, | Grade A | .. | 5000 pounds per square inch |
| „ „ | Grade B | .. | 4000 „ „ „ |

The load is to be applied at a rate between 3000 and 6000 pounds per minute.

(*c*) *Dryness Correction.*—These compression tests are for timber containing 15 per cent. of moisture If the timber, when tested, contains more moisture the specified strengths are to be reduced by 230 pounds per square inch for every 1 per cent. increase of moisture above 15 per cent., and if the timber contains less moisture the specified strengths are to be increased at the same rate. The percentage of moisture is calculated on the weight of the dried sample.

(*d*) *Bending Test.*—Test pieces, 40 inches long by 2 inches deep by 1 inch wide, cut from samples parallel to the grain, are to be loaded so as to produce in the middle part a pure bending moment (without shear). The deflection of the part subject to simple bending is to be measured and the value of Young's modulus calculated from it.

The results must not be less than—

| | | | |
|---|---|---|---|
| Young's Modulus, | Grade A | .. | 1,600,000 pounds per sq. inch. |
| „ „ | Grade B | .. | 1,200,000 „ „ „ |

(e) *Splitting Test.*—Short samples, say 4 to 6 inches long, are to be split in two planes, one tangential and one radial. The split faces will show the true direction of the grain, which must not be inclined to the length of the plank by more than 1 in 20 for Grades A and B.

(f) *Brittleness Test.*—A standard notched test piece, when broken in a notched bar testing machine, must not absorb less than—

| | | |
|---|---|---|
| For Grade A timber | .. .. .. | 8 foot-pounds |
| „ B „ | .. .. .. | 4 „ |

When a suitable testing machine is not available, the test piece is to be broken by a blow with a hammer, and the fracture must show a satisfactory amount of fibrous splinter.

## British Standard Specification* for Aircraft Material.

### *Walnut.*

1. Quality.—The timber shall be butt lengths of walnut (*Juglans*) of any of the following species, viz.: American black walnut (*Juglans nigra*, L.), European or Asiatic walnut (*Juglans regia*, L.), or Kurumi walnut (*Juglans sieboldiana*, Maxim) from Japan.

African walnut (*Khaya sp.*) and "satin walnut" (properly called *Red Gum*) are not included in this specification.

(*Note.*—The timber shall preferably be cut from trees that have been felled during the leafless season.)

2. Weight per Cubic Foot.—The weight per cubic foot of the timber shall be not less than 35 pounds, when the moisture content is 15 per cent.

3. Seasoning.—The timber shall be naturally seasoned if possible. If kiln-dried timber is used, the following conditions shall be complied with—

(i) The timber shall be dried in an approved kiln.
(ii) Autographic records shall be kept showing the temperature and humidity conditions during the process.
(iii) The maximum temperature shall not exceed 125° F.
(iv) The moisture content at the conclusion of the process shall be as follows—

| | | | |
|---|---|---|---|
| Summer (Mid. April to Mid. Oct.) | not more than | 18 per cent. | and |
| | not less than | 12 „ | |
| Winter (Mid. Oct. to Mid. April) | not more than | 16 „ | and |
| | not less than | 10 „ | |

4. Dryness of Timber.—The timber shall not be reduced to its final shape and size until the moisture has been reduced to 13 per cent. or less, nor shall any parts of the wood be glued together until this degree of dryness is attained.

5. Dryness Tests.—*Selection of Test Pieces.* Samples shall be cut from the timber, whether unseasoned or seasoned, and shall be tested for moisture content.

6. Conversion.—Logs containing a simple bend shall be planked so that planks are produced parallel to the plane of the bend. Irregular and curved parts should, as far as possible, be obtained from timber

* British Engineering Standard Association, 1918.

having naturally curved grain, so that the grain of the wood is continuous throughout the length of the part. Walnut, however, bends readily when steamed, and parts may be bent when necessary.

7. Straightness of Grain.—The maximum inclination of the grain to the length of the part shall not exceed 1 in 12.

8. Freedom from Defects.—The timber shall contain no deleterious knots or shakes, curls, burrs, rammy figure, caney grain, nor show signs of prolonged weathering, mildew pock, dead streak, or other forms of rot. Sapwood may be permitted in any part if it is sound, bright, tough, and strong. Pinholes, if not too large or numerous, may be permitted.

(*Note.*—Wide-ringed material is usually heavier and is the tougher and better material.)

9. Mechanical Tests.—*Notched Bar Tests for Brittleness.* A standard test piece, when tested in an impact testing machine, shall not absorb less than 9 foot-pounds. The sides of the test piece shall be cut radially and tangentially, and the blow shall be applied in the tangential direction.

(*Note.*—Where a suitable machine is not available, the test piece shall be broken by a blow with a hammer. The fracture shall show a satisfactory amount of fibrous splinter.)

## Timber Measures.

| | | |
|---|---|---|
| One load | = | 40 cubic feet of unhewn timber |
| | = | 50 cubic feet of squared timber |
| | = | 600 superficial feet of 1 inch planks |
| | = | 300 superficial feet of 2 inch planks |
| | = | 150 superficial feet of 4 inch planks |
| One hundred | = | 120 deals (not over 9 inches wide) |
| One square | = | 100 superficial of flooring |
| | = | 12¼—12 feet deal boards, rough |
| | = | 12½—12 feet deal boards, shot edges |
| | = | 14 —12 feet deal boards, wrought, ploughed, and tongued |
| | = | 16 —12 feet battens, rough |
| | = | 16½—12 feet battens, shot edges |

Deals are not over 9 inches wide. Battens are not over 7 inches wide. Planks are usually 11 inches wide. Planks, deals, and battens are sold by the number contained in the cubic content of 6-score, or the long hundred. Thus, the London standard consists of 120 pieces, each measuring 12 feet × 3 feet × 9 inches, which is equivalent to 270 feet cube, or 1080 superficial feet.

The Quebec long hundred has 120 pieces, each 10 feet × 3 feet × 11 inches, equivalent to 275 feet cube, or 1000 superficial feet.

## American Hardwood Sizes.

### *National Hardwood Lumber Assoc. (Hughes).*

*Standard lengths* are 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, and 16 feet long; odd lengths must not exceed 15 per cent.

*Standard thicknesses* are ¼, ⅜, ½, ⅝, ¾, 1, 1¼, 1½, 1¾, 2, 2½, 3, 3½, 4, 4½, 5, 5½, and 6 inches.

STANDARD THICKNESSES OF SURFACED TIMBER.

| Rough size. | Surfaced size. | Rough size. | Surfaced size. |
|---|---|---|---|
| *Inches.* | *Inches.* | *Inches.* | *Inches.* |
| $\frac{3}{8}$ surfaced both sides | $\frac{[illegible]}{16}$ | $1\frac{3}{4}$ surfaced both sides | $1\frac{1}{2}$ |
| $\frac{1}{2}$ ,, ,, | $\frac{5}{16}$ | 2 ,, ,, | $1\frac{3}{4}$ |
| $\frac{5}{8}$ ,, ,, | $\frac{7}{16}$ | $2\frac{1}{2}$ ,, ,, | $2\frac{1}{4}$ |
| $\frac{3}{4}$ ,, ,, | $\frac{9}{16}$ | 3 ,, ,, | $2\frac{3}{4}$ |
| 1 ,, ,, | $\frac{[illegible]}{16}$ | $3\frac{1}{2}$ ,, ,, | $3\frac{1}{4}$ |
| $1\frac{1}{4}$ ,, ,, | $1\frac{[illegible]}{32}$ | 4 ,, ,, | $3\frac{3}{4}$ |
| $1\frac{1}{2}$ ,, ,, | $1\frac{11}{32}$ | | |

Timber surfaced on one side is $\frac{1}{16}$ inch full of above thicknesses.

SOFTWOOD SIZES.—Common lengths in multiples of 2 feet. Smallest length, 4 feet.

# CHAPTER VI

# THE TESTING OF TIMBER

## GENERAL CONSIDERATIONS

METALS are practically homogeneous in constitution; the differences in the mechanical properties in different directions are usually quite small; thus, in the case of metal sheets the difference in the tensile strength along and across the direction of rolling usually only amounts to about 5 or 10 per cent.

The variations in the tensile strengths of timber along and across the grain amount to several hundred per cent. in most cases; whilst the strengths in different directions are invariably different. The variation of the strength of timber in different directions is, of course, due to its heterogeneous constitution, the wood fibres, which contribute most towards the strength, lying longitudinally and parallel to the axis of the tree.

The mechanical strength properties of timber are dependent upon a number of factors,* each of which must be taken into account in any comparative results. The variations in the test results for the same kind of timber taken from different sources are often very great, and the results of tests upon any one tree cannot be directly applied to any other. It becomes necessary to make a large number of tests upon timbers in order to obtain reliable average values, although carefully selected timber conforming to specification, as in aeronautical work, varies but little in its mechanical properties. In tests on timbers to be utilized for parts under stress, in aeronautical work, such as wing struts, fuselage struts and longerons, wing spars and similar members, it is usual to base the strength calculations upon considerations of the *minimum strength* found by a large number of tests upon specified test pieces.

## SIZE OF SPECIMEN

The size of the specimen has a marked influence upon its properties, in that small specimens usually give excess

* These factors are enumerated upon pp. 257 and 258.

strength values, as they are better seasoned, and more uniform in quality. The actual size of the test piece should be governed by the ultimate purpose of the timber, but it may be definitely stated that the larger the specimen, and the more it approximates in size to the actual object, the better.

The known variations in the structure of timber in different parts of a tree, due to its situation in the trunk, the presence of knots, shakes, and similar defects, are in favour of the use of large specimens for average results; the size of the test piece should invariably be mentioned with the test results.

In aeronautical timber testing it is often possible to test full-sized articles under the conditions of stress similar to those occurring on the machine. For example, compression tests may be made upon actual struts picked at random from finished batches.

It is more difficult, however, to test aeronautical parts under repeated stress action, such as the wing spars or longerons, although machines have been devised* for performing these tests; it is usually sufficient to determine the strength of the timber under the conditions causing the greatest stresses. In the case of aeroplane wing spars which are under repeated tension and bending, or compression and bending, the bending stresses are nearly always the more important.

In connexion with the effect of size upon strength, it has been shown† that the modulus of elasticity is about the same for large timbers as for small uniform specimens cut therefrom, and that crushing tests upon small-sized specimens furnish fairly reliable information as to the fibre stress at the elastic limit for large beams.

## FACTORS AFFECTING THE STRENGTH OF TIMBERS

The mechanical properties of timber are dependent upon a number of factors, of which the more important may be enumerated as follows—viz.: (1) *The Mode of Growth of the*

* Tests have been made upon wing spars repeatedly loaded in opposite directions, similar to the flight loadings, at the N.P.L.

† U.S. Forestry Service Bulletin, No. 108, p. 53.

*Timber* ; (2) *The Rate of Growth* ; (3) *The Position of the Timber in the Tree* ; (4) *The Season of Felling* ; and (5) *The Seasoning Process** *or Moisture Content.*

For a proper understanding of the influence of these factors, the internal structure of the various timbers should be carefully studied.†

The present information as to the relation between the mechanical strength, structure, and chemical composition, cannot be regarded as being complete in the true sense of the word, but rather as being generally indicative of the influences of the factors concerned.

## 1. The Mode of Growth of Timber.

The strength properties of a timber will depend upon the manner in which it was grown—that is to say, upon the locality in which the tree grew, the soil, and climate.

Trees grown out in the open are usually of better timber quality than forest-grown ones, although in exposed places the timber may be subject to defects such as windshakes. The more uniform the growth conditions, the more uniform become the annual rings and the quality of the timber. In the case of trees grown on the edges of woods, the annual rings are eccentric, the rings being wider on the outside.

The strength differences found in the case of some timbers, such as the longleaf pine, grown in different localities and under different conditions of soil and climate, are usually very small, and may, in fact, be classed more as individual differences. In the case of other timbers, such as the shortleaf pine and hickory, grown in different parts of the United States, the effect of mode of growth is evident. Thus, the former timber, as grown in the southern coast and gulf region, is heavier and stronger than that grown in the northern regions.

In the case of hickories, the southern region timber is more porous and shaky than the northern timber, although the strengths of selected sound timbers of the same age from both

* The preservation process also affects the weight and strength of timber considerably.

† See Chapter V.

regions are the same. Hickory grown in wet and moist soil is inferior to that grown on drier and fresher land.

## 2. Effect of Rate of Growth.

The yearly amount of growth of a tree is represented by the material between the annual rings, and the most recent growth is the woody material layer between the outermost ring and the inner bark. The wood formed in the earlier part of the year is known as the *early wood*, whilst that formed in the late year is called the *late wood*. There is not much difference between the two woods in the case of soft pines, the texture being fairly uniform. In the case of hard pines, however, the early wood is much softer and lighter in colour, the late wood being hard and dark; and the heavier* the timber of the same hard pines, the greater is the proportion of the late-grown wood.

The strength of timber of the same species is largely dependent upon the proportion of late to early material, as distinct from the actual width of the rings, although the actual quality of this material is also important.

The following is a summary† of tests made by the U.S. Forestry Service upon the effect of growth rate upon the quality and strength of Douglas fir—

(1) Rapidly grown wood, having less than 8 annual rings per inch, is relatively weak.

(2) The best rate of growth for this timber gives from 12 to 16 rings per inch.

(3) The effect of slow growth is to produce an uniform timber possessing fairly constant weight and strength. The average strength diminishes somewhat as the number of rings increases from 16 to 24, above which the strength tends to become more constant.

* The strength of timber may be taken as varying with its density, other things being equal.

† "The Properties and Uses of Douglas Fir," U.S. Forestry Service Bulletin, No. 88. Also see p. 47 "The Mechanical Properties of Wood," S. J. Record. (J. Waley and Sons.)

The average growth rate, however, has very little effect upon the strength properties of large beams, owing to the individual variations in different parts balancing each other.

In timber specifications for aeronautical purposes it is now usual to specify the number of annual rings per inch, the following being typical instances—

TABLE LXXXIII.

SPECIFICATIONS FOR ANNUAL GROWTH RATE.

| *Material.* | *Specified Number of Annual Rings per Inch.* | *Authority.* |
|---|---|---|
| Ash .. .. .. .. | 6–16 | Aeronautical Specifications. |
| Spruce (sitka or silver) .. | 10–15 | |
| Douglas fir .. .. .. | 24 | U.S. Forestry Service Bulletin, No. 108. |
| Shortleaf pine .. .. | 12 | |
| Tamarack .. .. .. | 20 | |
| Norway pine .. .. | 18 | |

In the case of hardwoods, such as oak, ash, elm, and hickory, the effect of rapid growth is to lessen the number of annual rings per inch, and to produce heavier timber, possessing relatively greater hardness and strength. In certain hardwoods, such as oak, the strongest material is that lying between the annual rings, corresponding to summer growth, and the narrower the annual rings (due to slower growth) the less is the proportion of this summer material to the total, and the weaker, relatively, is the timber.

Some tests* made upon various hickories show that when hickory is fairly rapidly grown—that is, when the number of rings per inch lies between 5 and 14—the timber possesses the greatest resilience or shock-resisting strength. For very rapidly or very slowly grown wood the strength falls off. For a growth rate corresponding to between 14 and 20 rings per inch the mechanical strength is a maximum, and remains fairly

* "The Commercial Hickories," U.S. Forestry Service Bulletin, No. 80, p. 48.

constant. In the case of chestnut timber, the wider the annual rings the greater is the proportion of wood substance, and the heavier and stronger is the material. Rapidly grown chestnut, such as sprouts, therefore, yield better timber than the more slowly grown chestnut, such as seedlings.

### 3. The Effect of Locality in the Tree Itself.

The timber taken from different parts of the same tree varies considerably in quality, other factors remaining the same.

The rate of growth of the majority of trees is most rapid when they are young, and tends to remain fairly constant for a large number of years; but as the tree becomes old the rate of growth falls off, and the number of rings per inch diminish. The effect of rate of growth has already been considered in the preceding paragraph, and it has been shown that the weakest timber is that grown extremely rapidly or very slowly; it follows that the timber at the centre or near the bark of an old tree will not, in general, be so strong as that corresponding to the normal growth, lying between the centre and circumference.

The wood formed late in the life of old trees is almost invariably softer, lighter, and less strong, than that formed earlier, so that the sapwood of large trees is usually weaker in its mechanical properties than the heartwood. For trees of normal age the sapwood is generally as strong as the heartwood.

As the result of numerous tests* upon hickories, it was concluded that there was no difference in the strengths of white hickory (corresponding to sapwood) and dark or red hickory (corresponding to the heartwood), although in the case of large and old trees the lighter wood near the bark was weaker than the heartwood, whilst in the case of young trees the sapwood was the stronger.

For unpreserved timbers the sapwood is more liable to

* "The Commercial Hickories," U.S. Forestry Service Bulletin, No. 80, p. 50.

decay, but for preserved or seasoned timber the sapwood usually derives more benefit by the treatment and does not shrink so much, nor is it so liable to checks or defects.

**Effect of Knots.**—The presence of knots* in a tree will affect the strength of the timber there. The knots being due to the presence, at an earlier stage in its history, of twigs and branches which have subsequently died off or broken, the heartwood may contain knots, whereas the later sapwood may be fairly free from the same. As will be shown later, knots are usually places of weakness, and it follows that from this point of view the sapwood is the stronger.

For timber parts in bending action knots are a serious defect when they are situated upon the tension side of the beam, since the tensile strength of a piece of wood with a large knot is extremely low. The presence of a knot upon the compression side is not very detrimental, as a rule. When knots occur near the neutral axis they may actually increase the strength of the beam by offering greater resistance to shearing.

The effect of knots is not very marked upon the stiffness of beams, nor upon the compressive strength parallel to the grain, but in the case of beams the moduli of rupture (or coefficients of breaking strength) are lower in value according to the size and distribution of the knots. The value of the modulus of elasticity is not appreciably affected, unless the knots are a large percentage of the specimen material.

Knots offer a *greater resistance* to *shearing stress*, abrasive or wearing action,† and to cleavability.

**Position along Trunk.**—The strength of timber is also dependent, to some extent, upon its situation along the trunk of the tree. The wood nearer the roots and the upper branches is, in general, the weaker, and, moreover, is more liable to

* See p. 204.

† It is a common fact that timber, especially floor-boarding, wears least where the knots are.

defects, such as cross-grain and spiral grain, shakes, and branch outlets.

The following table represents the results of about 2000 tests made upon longleaf pine derived from 26 different trees, and shows that for this timber the middle logs are, upon the average, the stronger in bending strength and shear, whilst for the butt logs the tensile and compressive strengths are the greater.

TABLE LXXXIV.

TEST RESULTS FOR LONGLEAF PINE.
(U.S. Department of Agriculture.)

| *Position on Trunk.* | *Weight. Pounds per Cubic Foot.* | *Modulus of Elasticity from Bending Tests.* | *Modulus of Rupture or Coefficient of Bending Strength.* | *Crushing Strength.* | *Tensile Strength.* | *Shearing Strength.* |
|---|---|---|---|---|---|---|
| | | Tons per Sq. In. | Tons per Sq. In. | Tons per Sq. In. | Tons per Sq. In. | Tons per Sq. In. |
| Butt logs .. | 28–64·8 | 500–1380 | 2·12–7·25 | 2·13–4·40 | 3·84–14·4 | 0·21–0·58 |
| Middle logs | 36–53·5 | 510–1360 | 3·40–7·65 | 2·25–4·15 | 2·82–13·4 | 0·24–0·55 |
| Top logs .. | 32–56·5 | 375–1200 | 1·90–7·00 | 2·04–4·06 | 1·85–10·8 | 0·22–0·52 |

If, as is often the procedure, the range of variation and the minimum strength values are the governing factors, the middle logs are (with the single exception of the tensile strength) decidedly the better.

## 4. The Season of Felling.

It is known that timber obtained from winter-felled trees is, as a rule, stronger and more durable than from summer-felled trees, but the exact causes are not fully understood.

It has been maintained that in winter, when there are no leaves upon the tree, the sap is circulating at its minimum rate, whilst in summer the sap is at a maximum, but there is no direct confirmation of this belief. The present evidence points

to the conclusion that the accepted variations in winter and summer-felled timber are due rather to outside or weather conditions than to internal changes. Any changes that may occur, such as a variation in the chemical composition of the sap (there appears to be no evidence of quantitative variation), will affect only the outer layers or the sapwood alone, since the heartwood is in reality deadwood.

One important aspect of the season of felling is in connexion with the subsequent seasoning or shrinking for summer-felled timber will dry more rapidly, and will therefore be more liable to checks and defects than the more slowly and more uniformly drying winter-felled wood. Moreover, there is less danger of fungus or sap-rot and insect attack in winter, so that the bulk of the evidence is in favour of winter felled timber.

## TABLE LXXXV.

### RESULTS OF TESTS UPON SUMMER AND WINTER-FELLED TIMBER. (Bauschinger.)

| *Material.* | *Tensile Strength in Tons per Square Inch.* | | *Moisture per Cent.* | *Compressive Strength in Tons per Square Inch.* | | *Moisture per Cent.* | *Bending Strength in Tons per Square Inch.* | | *Moisture per Cent.* |
|---|---|---|---|---|---|---|---|---|---|
| | Summer-Felled. | Winter-Felled. | | Summer-Felled. | Winter-Felled. | | Summer-Felled. | Winter-Felled. | |
| Red pine | 5·01 | 3·78 | — | 1·78<br>2·37 | 2·03<br>3·20 | 19–26<br>10 | 3·00 | 2·86 | 23–33 |
| Spruce from four different localities in Germany. | 5·20 | 5·22 | — | 1·36<br>1·98<br>2·06*<br>2·73† | 1·73<br>2·27<br>2·45*<br>2·69† | 17–27<br>10<br>10<br>10 | 2·39 | 2·44 | 23·5-29 |

*Note.*—The size of the test pieces varied from 1·6 × 0·4 inch section for the tension test to 3½ × 3½ × 6 inches long for the compression test, and to 7½ × 7½ × 98 inches span for the bending test, and the tests were made three months after felling.

* Tests made upon whole section of log after three months' seasoning.
† Tests made upon whole section of log after five years' seasoning.

### 5. Effect of Seasoning or Moisture Content.

The strength of a given timber depends upon its dryness—that is to say, upon the percentage of moisture in the wood. The drier the timber, the stronger it is in bending, tension, compression, and shear, and also the harder it becomes.

The effect of moisture in timber is to impregnate the cells and cell cavities, and to soften the wood substance in such a manner that its strength is diminished. It is now usual to specify the percentage of water permissible in timber tests, and a standard dryness of about 10 to 12 per cent. is generally accepted as representing the condition of well air-dried or seasoned timber.

The following table illustrates the effect of moisture content upon the strength of timber, and it will be observed that the compression strength (parallel to the grain) is the most affected by moisture—

TABLE LXXXVI.

EFFECT OF DRYNESS UPON MECHANICAL PROPERTIES OF TIMBER.

(U.S. Forestry Service Bulletin, No. 70.)

| *Mechanical Properties.* | *Ratio of Strength in the 3·5 per Cent. Dry Condition to the Strength in the Green Condition.** | | |
|---|---|---|---|
| | *Longleaf Pine.* | *Spruce.* | *Chestnut.* |
| Crushing strength parallel to grain .. | 2·89 | 3·71 | 2·83 |
| Elastic limit in compression parallel to the grain | 2·60 | 3·80 | 2·40 |
| Crushing strength at right angles to the grain | — | 2·58 | — |
| Modulus of elasticity in compression parallel to the grain | 1·63 | 2·26 | 1·43 |
| Modulus of rupture or bending coefficient | 2·50 | 2·81 | 2·09 |
| Stress at elastic limit in bending .. | 2·90 | 2·90 | 2·30 |
| Modulus of elasticity in bending .. | 1·59 | 1·43 | 1·44 |
| Shearing strength parallel to the grain | 2·01 | 2·03 | 1·55 |

* The values given refer to green and dry specimens of equal size.

In connexion with the values given in the above table, it should be noted that 3·5 per cent. dry timber is much drier than ordinary air-dried or seasoned timber, so that the percentage increments in strength properties will not be so high for the latter.

The following tables give the strength values for the two given timbers for different degrees of moisture—

## TABLE LXXXVII.

### Longleaf Pine.

| | *Moisture Condition.* | | | | | |
|---|---|---|---|---|---|---|
| | *Kiln-Dry.* 6·2 *per Cent.* | 9·5 *per Cent.* | 11·5 *per Cent.* | 14 *per Cent.* | *Green.* 23 *per Cent.* | *Water-Saturated.* 50 *per Cent.* |
| Fibre stress at elastic limit in bending (pounds per square inch) | 11,550 | 9280 | 7842 | 6924 | 5944 | 4920 |
| Compressive strength (pounds per square inch) | 10,910 | 8955 | 7466 | 6466 | 5100 | 4668 |

## TABLE LXXXVIII.

### Spruce.

| | *Moisture Condition.* | | | | |
|---|---|---|---|---|---|
| | *Kiln-Dry.* 3·9 *per Cent.* | 8·1 *per Cent.* | 10 *per Cent.* | *Green.* 30 *per Cent.* | *Water-Saturated.* 30 *per Cent.* |
| Fibre stress at elastic limit in bending (pounds per square inch) | 10,170 | 8400 | 6458 | 3362 | 3002 |
| Compressive strength (pounds per square inch) | 9335 | 7610 | 6120 | 3025 | 2680 |

It will be observed that the compressive strength is, upon the average, about 10 per cent. lower than the elastic limit fibre stress; the crushing tests were made upon short pieces of the same material as used in the bending tests.

The crushing test may therefore be used as a means for determining the bending strength.

When timber is heated in the wet or green condition its strength diminishes; thus, when seasoned wood is steamed for a few hours its bending strength is diminished by from 20 to 40 per cent., and its crushing strength by about the same amount. The strength of timber which has been steam-bent and then dried is always less than in the original dry state. The effect of cold is to increase the strength and stiffness of timber of all degrees of dryness, the effect being greater for wetter woods.

**Effect of Density* upon Strength.**

For the same timber and the same moisture content it has been shown that the strength properties increase with the density of the timber (as shown in Fig. 78), when the density is due to increased weight of, or proportion of wood substance. Thus, the strength of a specimen of timber of standard dryness may be inferred from that of another specimen of the same species, but of different density.

There is, further, an approximate relation between the strengths and the densities of timbers of different species under given conditions of dryness, but in most cases the proportionality does not follow a simple law.

The principal effect of density in a given species or in different species is to cause the hardness and resistance to abrasion to be nearly proportional to it. The crushing strength, fibre stress at elastic limit, and the shearing strength for timber of a given dryness is practically proportional to the density.

It has also been deduced from numerous test results that the modulus of rupture increases at a rather higher rate

* The density is here defined as the weight per unit volume; the volume usually taken is that of a cubic foot.

than the density. Approximately, the relation is as follows:

$$p = k \cdot \rho^{1 \cdot 5},$$

where $p$ = modulus of rupture, $\rho$ = density, and $k$ = a constant depending upon the timber.

The results of tests upon twenty-six species of American

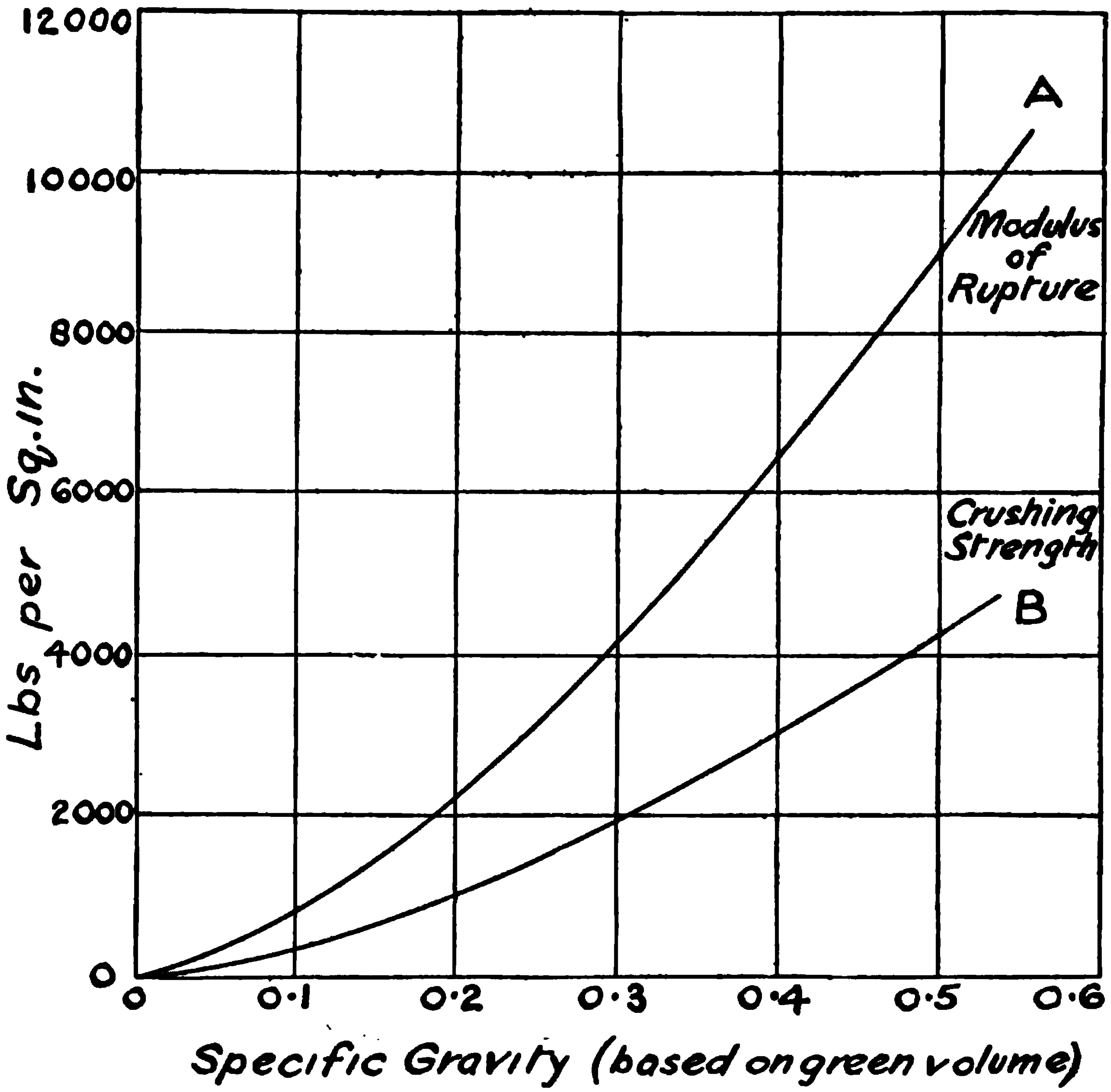



FIG. 78.—SHOWING THE EFFECT OF DENSITY UPON THE STRENGTH OF SILVER SPRUCE.

woods,* all of about 15 per cent. moisture show that within limits the following relations hold—namely:

| | |
|---|---|
| (1) The compression strength parallel to the grain | $= \text{S.G.} \times 10^4$. |
| (2) The modulus of rupture | $= \text{S.G.} \times 2 \times 10^4$. |
| (3) The modulus of elasticity | $= \text{S.G.} \times 2{\cdot}8 \times 10^6$. |

* G. H. Congdon, *Aviation*, March 15, 1918.

For red, Sitka, and white spruces the following relations hold:

(*a*) Modulus of rupture (pounds per square inch)

$$= 25{,}000\ \sqrt{(\text{S.G.})^3}$$

(*b*) Maximum crushing strength (pounds per square inch) .. .. .. .. $= 12{,}000\ \sqrt{(\text{S.G.})^3}$

Table LXXXIX. gives the approximate effects of variations in dryness and density, etc., upon the mechanical properties of good samples of timbers as deduced from the results of a large number of U.S. Forestry Service tests.*

The strength properties of different timbers have been shown to be dependent upon several major factors, but there are many minor factors also which should not be lost sight of in analyzing and comparing the results of timber tests. These include structure of the timber (that is, whether straight, wavy, curly-grain, burred), presence of frost, wind and other shakes, galls, pitch-pockets, insect and fungus injuries, etc.

## The Principal Timber Tests.

The principal tests to which timber is subjected for commercial purposes may be enumerated as follows—namely, tests for: (1) *Specific Gravity*; (2) *Percentage of Moisture*; (3) *Tensile Strength and Elasticity*; (4) *Compressive Strength* both for long and short specimens; (5) *Bending Strength, Elasticity*, and *Deflection*; (6) *Shearing Strength*; (7) *Impact Test*; (8) *Hardness*; (9) *Wearing* or *Abrasive Action*; (10) *Resilience*—that is, the capacity for storing energy; and (11) *Cleavability*, or resistance to splitting.

There are, of course, many other tests applied to timber in special instances, such as the Repeated Impact Test, Torsion Test, Combined Stress Tests, Warping, Weathering, and similar tests, but the above list may be taken as being a representative one.

* U.S. Forestry Service Bulletin, No. 556.

## TABLE LXXXIX.

### Effect of Variations in S.G., Moisture, etc., upon the Mechanical Strength Properties of Timber.

| *Property.* | *Average Variation in Value effected by varying the Moisture Content by 1 per Cent. when at about 12 per Cent.* | *Approximate Power of Specific Gravity according to which Property varies.* | *Probable Variation of Present Average (when from 5 Trees) from True Species Average.* | *Probable Variation of Random Tree from Average for Species.* |
|---|---|---|---|---|
| | *Per Cent.* | | *Per Cent.* | *Per Cent.* |
| Specific gravity based upon green volume | — | — | 1·7 | 3·8 |
| Weight per cubic foot .. | — | — | — | — |
| Shrinkage .. .. | — | 1 | — | — |
| *Static Bending :* | | | | |
| Fibre stress at elastic limit | 6 | 1 | 5 | 12 |
| Modulus of rupture .. | 4 | 1 | 4 | 9 |
| Modulus of elasticity .. | 2 | 1 | 5 | 11 |
| Work to elastic limit .. | 8 | 2 | 7 | 16 |
| Work to maximum load | − 1 | 2 | 6 | 14 |
| *Impact Bending :* | | | | |
| Fibre stress at elastic limit | 4 | 1 | 4 | 8 |
| Work to elastic limit .. | 5 | 2 | 5 | 12 |
| Height of drop .. .. | − 3 | 2 | 7 | 15 |
| *Compression Parallel to Grain :* | | | | |
| Fibre stress at elastic limit | 5 | 1 | 5 | 12 |
| Crushing stress .. | 4 | 1 | 4 | 9 |
| *Compression Perpendicular to Grain :* | | | | |
| Fibre stress at elastic limit | 6 | 2 | 6 | 14 |
| Hardness, end .. .. | 3 | 2 | 4 | 9 |
| Hardness, side .. .. | 1 | 2 | 5 | 10 |
| Shearing strength parallel to grain | 4 | 1 | 3 | 7 |
| Tension perpendicular to grain | 1 | 2 | 5 | 12 |

**Specific Gravity.**

The specific gravity may be defined as the ratio of the weight of a given volume of the timber to that of an equal volume of water (at a given temperature).

The specific gravity of different timbers varies from about 0·011 in the case of Balsa up to 1·2 in the case of ebony. The variation in the specific gravities of the different timbers is due to the different proportions of the wood substance, air spaces, resin ducts, etc., in the different species; the specific gravity of the wood substance for nearly all timbers is constant and is about 1·55.

The specific gravity of timber of a given kind may vary considerably, depending upon the age, rate and mode of growth, the part of the tree from which it is taken, and the moisture content.

Thus, in the case of English oak, the density in the green state varies from 62 to 66 pounds per cubic foot, whilst in the seasoned state (10 to 12 per cent. moisture) it weighs from 53 to 58 pounds per cubic foot.

Very dry oak weighs from 44 to 47½ pounds per cubic foot, whilst the wood of very old oak has a density of from 37½ to 39½ pounds per cubic foot. For the same timber a low specific gravity corresponds with the wood of an old tree.

It is usual to state the specific gravity or density of timber for testing purposes, and any other information bearing upon the factors mentioned in the preceding paragraph.

The principal variation in the specific gravity of a given timber is due to moisture variation; in the green state the sapwood may consist of half water and the heartwood of between 20 and 35 per cent. The amount of moisture present in the green state is very variable, so that for most commercial and technical purposes the specific gravity of timber of a stated dryness is always understood. For scientific work the standard dryness, known as "oven-dry" or "kiln-dry," is that of wood dried for at least twenty-four hours in an oven or kiln at 100° C., or 212° F.

For commercial purposes the density of "shipping-dry" or "air-dry" timber is that of freshly seasoned wood.

The specific gravity of dry wood is generally accepted as being taken in reference to actual dried volume, and not to the green volume, which is always much greater.

In drying or seasoning from the green state the volume may shrink by from 5 to 40 per cent. for exceptional cases; in normal cases for *hardwoods* the *shrinkage* is about 10 per cent., whilst for *softwoods* it is about 15 per cent.

The simplest method for ascertaining the specific gravity of a given sample of wood of known dryness is to cut out a rectangular block and weigh same. If $l$, $b$, and $d$ inches be the length, breadth, and depth of the block, respectively, and $W$ be its weight in pounds, then the weight of an equal volume of fresh water will be $w=\frac{lbd}{1728}\times 62{\cdot}43$ pounds.

$$\text{The specific gravity is then given by S.G.}=\frac{W}{w}$$

$$=27{\cdot}69\,\frac{W}{lbd}.$$

$$\text{The density}=\frac{1728\,W}{lbd}\ \text{pounds per cubic foot.}$$

Another method of finding the specific gravity is to lightly varnish the wooden block, so as to prevent water absorption, and to place same in a vessel previously filled with water, and fitted with a lid as shown in Fig. 79, and overflow. The weight of water $W_w$ displaced by the block can then be readily measured.

The specific gravity $=\frac{W}{W_w}$, where $W=$weight of block.

The density $=\frac{W}{W_w}\times 62{\cdot}43$ pounds per cubic foot.

The table* on page 273 gives a few typical specific gravities for green and dry timbers, together with their percentage shrinkages† in the three directions indicated.

* U.S. Forestry Service Circular 213.

† The subject of seasoning shrinkages is considered more fully upon p. 196.

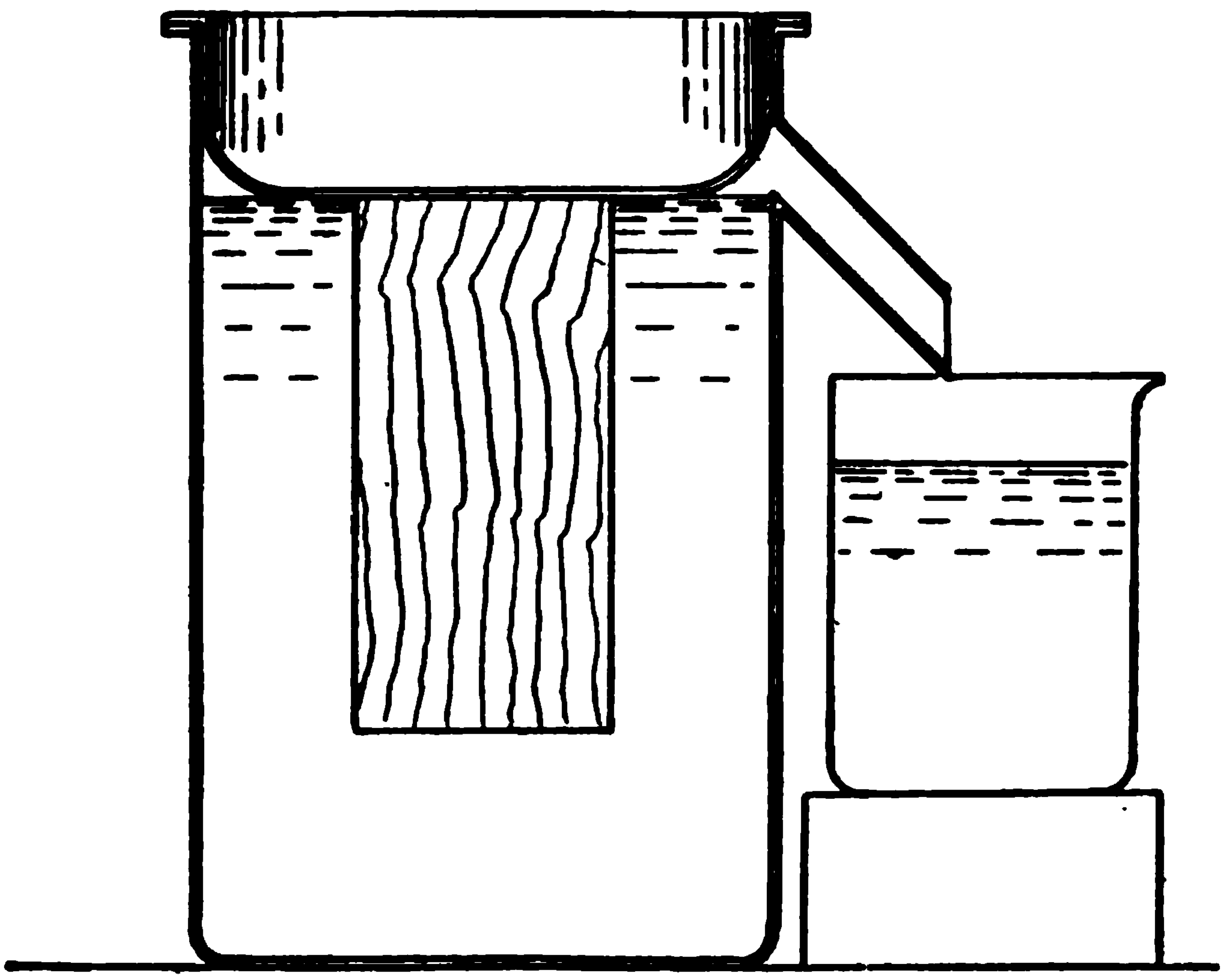


FIG. 79.—ILLUSTRATING METHOD OF FINDING THE DENSITY OF TIMBER.

## TABLE XC.

SPECIFIC GRAVITY AND SHRINKAGE OF TIMBER FROM GREEN TO DRY CONDITION.

| *Name.* | *Moisture per Cent.* | *Specific Gravity based on—* | | *Shrinkage from Green to Oven-Dried Condition.* | | |
|---|---|---|---|---|---|---|
| | | *Volume when Green.* | *Volume when Oven-Dry.* | *In Volume.* | *Radial.* | *Tangential.* |
| White ash .. | 38 | 0·550 | 0·640 | 12·6 | 4·3 | 6·4 |
| Basswood .. | 110 | 0·315 | 0·374 | 14·5 | 6·2 | 8·4 |
| Beech .. .. | 61 | 0·556 | 0·669 | 16·5 | 4·6 | 10·5 |
| Birch, yellow .. | 72 | 0·545 | 0·661 | 17·0 | 7·9 | 9·0 |
| Elm, rock .. | 46 | 0·578 | — | — | — | — |
| Hickory, mockernut | 64 | 0·606 | — | 16·5 | 6·9 | 10·4 |
| Hickory, pig-nut | 59 | 0·627 | — | 15·0 | 5·6 | 9·8 |
| Maple sugar .. | 57 | 0·546 | 0·643 | 14·3 | 4·9 | 9·1 |
| Oak, white .. | 62 | 0·603 | 0·696 | 14·3 | 4·9 | 9·0 |
| Cedar, incense .. | 80 | 0·363 | — | — | — | — |
| Fir, Douglas .. | 32 | 0·418 | 0·458 | 10·9 | 3·7 | 6·6 |
| Pine, longleaf .. | 63 | 0·528 | 0·599 | 12·8 | 6·0 | 7·6 |
| Pine, Norway .. | 54 | 0·440 | 0·507 | 11·5 | 4·5 | 7·2 |
| Pine, yellow .. | 98 | 0·353 | 0·355 | 9·2 | 4·1 | 6·4 |
| Spruce, white .. | 41 | 0·396 | — | — | — | — |
| Spruce, red .. | 31 | 0·318 | — | — | — | — |
| Tamarack .. | 52 | 0·491 | 0·558 | 13·6 | 3·7 | 7·4 |

## TABLE XCI.

EFFECT OF DRYING UPON COMMON TIMBER DENSITIES.

| *Name of Wood.* | *Weight per Cubic Foot, in Pounds.* | |
|---|---|---|
| | *Green Condition.* | *Air-Seasoned.* |
| Ash .. .. .. .. | 43¾–63½ | 32½–59 |
| Beech .. .. .. .. | 56¼–63½ | 41–52 |
| Oak .. .. .. .. | 58¼–63 | 43–62½ |
| Fir, Riga .. .. .. | 33¾–63¾ | 31¾–41 |

It will be observed that in the green condition the specific gravity varies from 0·53 to about 1·03, the maximum value approaching that of water. As the specific gravity of the wood substance is 1·55, the remaining substances, other than the water content, must have a much lower specific gravity. It is known that there are a number of air cells within the structure to partially account for this effect.

### Percentage of Moisture.

It has already been stated that the density of timber depends upon the moisture percentage, and that the strength also increases as the moisture content becomes smaller; it now remains to consider methods of measuring the percentage of moisture present.

The usual method adopted is to drill shavings out of the test block, or to cut discs or strips from 1 inch to 1½ inches thick from the outside and middle of the block, and to weigh same before and after drying in an oven kept at a constant temperature of 100° C. (or 212° F.) for such a period that the weight does not vary by more than 0·5 per cent. in twenty-four hours. The moisture percentage is then reckoned upon the dry weight. Thus, if $W_G$ = green weight, or weight before drying, and $W_D$ be the weight after drying,

$$\text{Then percentage moisture} = \frac{W_G - W_D}{W_D} \cdot 100.$$

## TABLE XCII.

DENSITY AND SPECIFIC GRAVITY OF COMMON TIMBERS.

| *Timber.* | *Specific Gravity.* | *Density.* Weight per Cubic Foot, in Pounds. | *Density.* Weight per Cubic Inch, in Pounds. |
|---|---|---|---|
| Ash From | 0·690 | 43 | 0·025 |
| Ash To | 0·760 | 47 | 0·027 |
| Balsa | 0·112 | 7 | 0·004 |
| Beech From | 0·690 | 43 | 0·025 |
| Beech To | 0·700 | 43·5 | 0·025 |
| Cork From | 0·225 | 14 | 0·008 |
| Cork To | 0·250 | 15·5 | 0·009 |
| Cypress | 0·465 | 29 | 0·017 |
| Cedar, American | 0·554 | 35 | 0·020 |
| Cedar, Indian | 0·748 | 47 | 0·026 |
| Cedar, Lebanon | 0·486 | 30 | 0·017 |
| Elm, English | 0·553 | 34 | 0·020 |
| Elm, American | 0·725 | 45 | 0·026 |
| Hickory From | 0·660 | 41 | 0·024 |
| Hickory To | 0·860 | 54 | 0·031 |
| Greenheart | 1·150 | 72 | 0·042 |
| Larch From | 0·543 | 34 | 0·019 |
| Larch To | 0·556 | 35 | 0·020 |
| Maple | 0·675 | 42 | 0·025 |
| Mahogany, Honduras | 0·560 | 35 | 0·020 |
| Mahogany, Spanish | 0·852 | 53 | 0·031 |
| Pine, white From | 0·432 | 27 | 0·015 |
| Pine, white To | 0·553 | 34 | 0·020 |
| Pine, longleaf | 0·608 | 38 | 0·022 |
| Pine, yellow | 0·508 | 32 | 0·018 |
| Poplar | 0·390 | 24 | 0·014 |
| Oak, white | 0·800 | 50 | 0·029 |
| Oak, red | 0·720 | 45 | 0·026 |
| Satinwood | 0·960 | 60 | 0·035 |
| Spruce, fir | 0·512 | 32 | 0·018 |
| Teak | 0·800 | 50 | 0·029 |
| Walnut, English | 0·670 | 42 | 0·024 |
| Ebony | 1·170 | 73 | 0·042 |
| Lignum vitæ From | 0·790 | 49 | 0·028 |
| Lignum vitæ To | 1·610 | 89 | 0·052 |

*Note.*—In most cases a moisture content of 10 per cent. is understood.

### Straightness of Grain.

In cases in which the grain is wavy or spiral, the tensile strength, elastic modulus, and modulus of rupture are all lower in value than for straight-grained timber. For most aircraft work it is very important that the grain should be

straight and parallel to the axis of tension or compression, or parallel with one or other of the sides; several accidents to wooden parts of aircraft have been traced, in the past, to the employment of wavy-grained material.

A simple test for straightness of grain, and one which is often employed in connection with aircraft timbers, is that known as the "splitting test." It consists in cutting off a small block from one end of the plank to be tested, and splitting this block in two directions at right angles with a chisel and mallet.

The direction of the sides of the split indicates the grain slope, and in the case of silver spruce it is officially specified* that the deviation from parallelism with the length of the plank should not exceed 1 in 20, whilst for ash it must be less than 1 in 10.

The length of test piece should be about 2 inches, and aircraft members when roughly machined or shaped are often left 2 inches longer for this reason.

It is of course assumed that the slope of the grain over the 2-inch length is the same as that over the whole plank's or member's length.

Probably the X-ray method of internal examination over the whole length is the most reliable one.

**Tensile Strength of Timber.**

The tensile strength of most timbers is greatest for the direction along the grain, and depends, in the same timber, upon the evenness and straightness of the grain.

The tensile strength across the grain is only a fraction of that along the grain, owing to the force acting perpendicular to the longitudinal fibres. Failure is usually due to the tearing apart of the fibres at the surfaces of the thin fibre walls, and is analogous to tearing apart a bundle of metal rods held together with relatively weak cement. The effect is very similar to that of cleavability. For most timbers the tensile strength across the grain is only from 2 to 3 per cent. in the

* See Specifications on pp. 244, 249 and 254.

case of softwoods, such as pines, and from 3 to 6 per cent. in the case of hardwoods, such as ash, beech, oak, and elm, of the strength along the grain.

On the other hand, the tensile strength along the grain is from 2½ and 3¾ times the compressive strength along the grain.

The effect, upon the tensile strength along the grain, of moisture is not nearly so marked as in the case of the bending, crushing, and shear strengths.

The tensile strength along the grain appears to be closely related to the real strength of the wood fibres, and for the same timber the greater the proportion of wood material, the higher will be its strength in tension. The nature, dimensions, and distribution of these fibres will naturally influence the tensile strength.

The fact of the tensile strength along the grain being much greater than the compressive and shear strengths makes the carrying out of tension tests a difficult matter, for the specimens cannot be properly gripped or held. The material, which has to be placed in the steel grips of the testing machine, should have at least 3½ times the cross-section of the actual area to be tested.

A method frequently employed for tensile tests is to enclose the enlarged ends of the specimen in strong metal boxes forming the shackles of the testing machine, and to clamp the ends in place by means of metal cover plates and bolts.

Fig. 80, Diagrams *A* and *B*, illustrates two different methods recommended for making tensile test specimens for tests along the grain. In the U.S.* method (Diagram *A*) the specimen consists of a circular rod of 1 inch diameter glued at the ends into corresponding holes in hardwood wedges which are then placed in the setting machine jaws. Diagram *B* illustrates the form of specimen employed by Professor Warren in connexion with tests upon Australian timbers. Tension tests across the grain are often made upon specimens

* U.S. Forestry Service Circular 38, "Instructions to Engineers of Timber Tests."

shaped as shown in Fig. 80, Diagram *C*, the grips having the shape shown dotted.

Tension tests are often omitted in timber specifications owing to the difficulties attendant, but in the special cases in which these tests are necessary the moisture content should be determined from the broken specimen immediately after the tests.

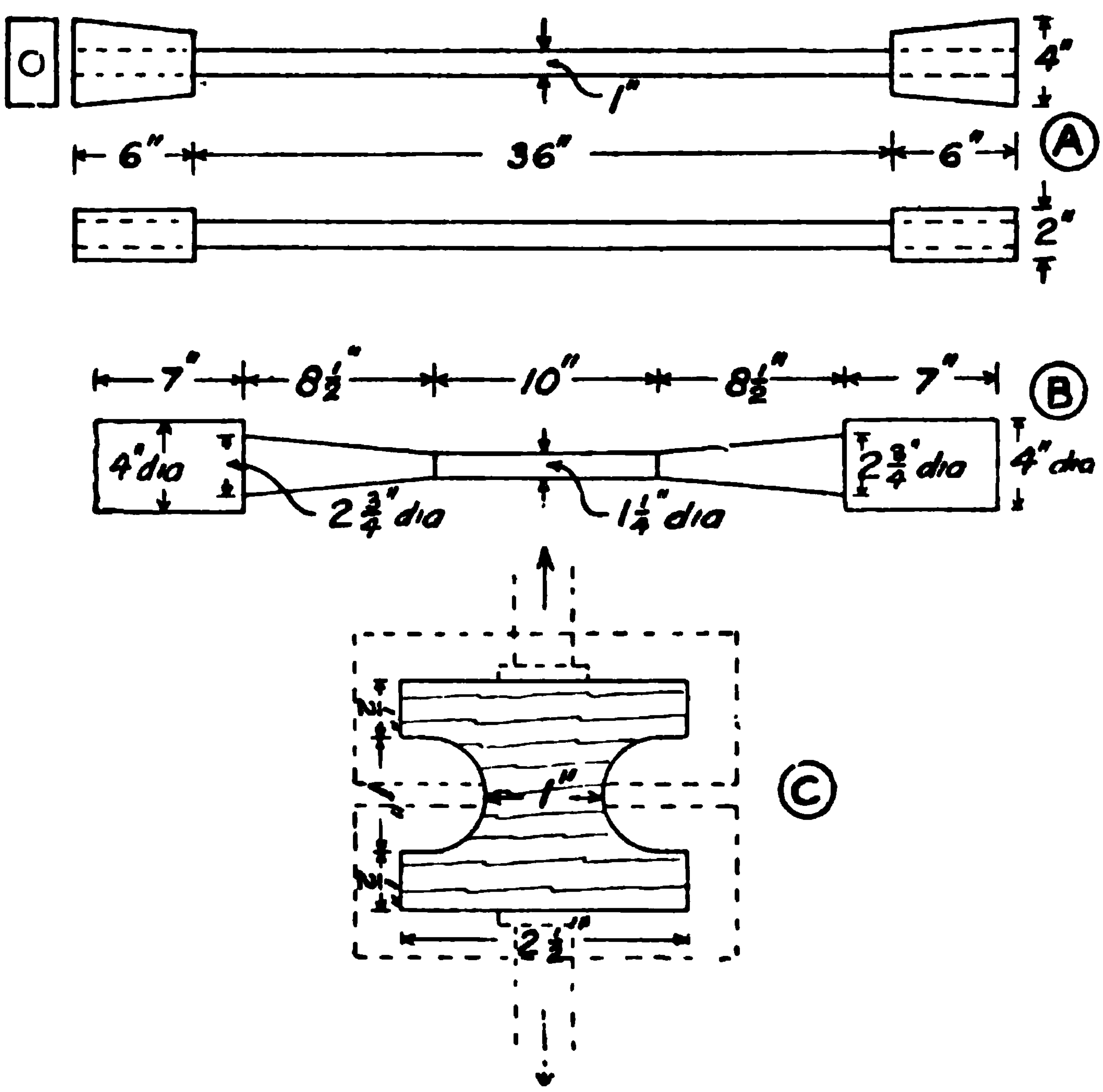



Fig. 80.

The *Modulus of Elasticity* for timber varies from about 750,000 up to about 1,900,000 pounds per square inch—that is to say, a linear strain of from $\frac{1}{750000}$ to $\frac{1}{1900000}$ inch would be produced by a tensile stress of 1 pound per square inch.

For most of the timbers employed for automobile or aircraft work the modulus of elasticity lies between 1,300,000 and 1,800,000 pounds per square inch.

Table XCIII gives the values of the moduli of elasticity for various timber, and represents the average values of the more reliable experimental results.

## TABLE XCIII.

MODULI OF ELASTICITY FOR DIFFERENT TIMBERS.

| *Kind of Wood.* | *Modulus of Elasticity. Pounds per Square Inch.* | *Kind of Wood.* | *Modulus of Elasticity. Pounds per Square Inch.* |
|---|---|---|---|
| Ash, American white | 1,416,000* | Mahogany, Honduras | — |
| Ash, English .. .. | 1,600,000 | Mahogany, Spanish .. | — |
| Basswood .. .. | 842,000* | Maple, red .. .. | 1,445,000* |
| Beech .. .. .. | 1,350,000 | Maple, sugar .. .. | 1,462,000* |
| Birch .. .. .. | 1,500,000 | Oak, African .. .. | 2,280,000 |
| Birch, American yellow | 1,597,000* | Oak, English .. .. | 1,450,000 |
| Cedar, incense .. | 754,000* | Oak, Post, American | 913,000* |
| Cedar, white .. .. | 750,000 | Oak, red, American .. | 1,268,000* |
| Cottonwood .. .. | 1,200,000 | Oak, white, American | 1,137,000* |
| Elm, English .. .. | 1,003,000* | Pine, longleaf .. | 1,662,000* |
| Elm, rock .. .. | 1,222,000* | Pine, Norway .. | 1,700,000 |
| Elm, slippery .. .. | 1,314,000* | Pine, pitch .. .. | 1,225,000 |
| Fir, Douglas .. .. | 1,242,000* | Pine, red .. .. | 1,384,000* |
| Fir, white .. .. | 1,131,000* | Pine, sugar .. .. | 966,000* |
| Greenheart .. .. | 1,747,000 | Pine, West yellow .. | 1,111,000* |
| Hickory, bitternut .. | 1,400,000* | Poplar, yellow .. | 1,300,000 |
| Hickory, mockernut .. | 1,508,000* | Spruce, Englemann .. | 866,000* |
| Hickory, shagbark .. | 1,752,000* | Spruce, red .. .. | 1,143,000* |
| Hickory, shellbark .. | 1,562,000* | Spruce, Sitka .. .. | 1,300,000 |
| Larch .. .. .. | 900,000 | Spruce, white .. | 968,000* |
| Mahogany, African .. | 1,400,000 | Walnut .. .. | 1,450,000 |

* Values deduced from bending tests made by U.S. Forestry Service.

### Bending Strength of Timber.

(*a*) **Method of Testing.**—Timber-bending tests are usually made upon rectangular beams, supported at the ends and loaded at the centre. The load should not be applied at a knife edge, otherwise failure by direct shearing or combined stress effect may result. It is usual to distribute the centre load over an area equal to the cross-section of the specimen by means of a steel plate or a pair of flat-faced roller blocks (as shown in Fig. 81, *A*). Another common test method, known as the third-point method, is to apply the load at

two points, dividing the beam into three equal parts (Fig. 81, *B*). The places of support are also provided with steel plates or rockers.

The standard size of test piece for aircraft woods is 40″ × 2″ × 1″, and for each kind of wood a minimum breaking load is specified; for example, in the case of ash, with a span of 24 inches (between the supports) and with the 2-inch side as the depth the minimum breaking load should not be less than 1,000 pounds, and the deflection at breaking not less than ¾ inch. In the case of silver spruce these values should not be less than 950 pounds and 1 inch respectively, and for propeller walnut 1250 pounds and ¾ inch respectively.

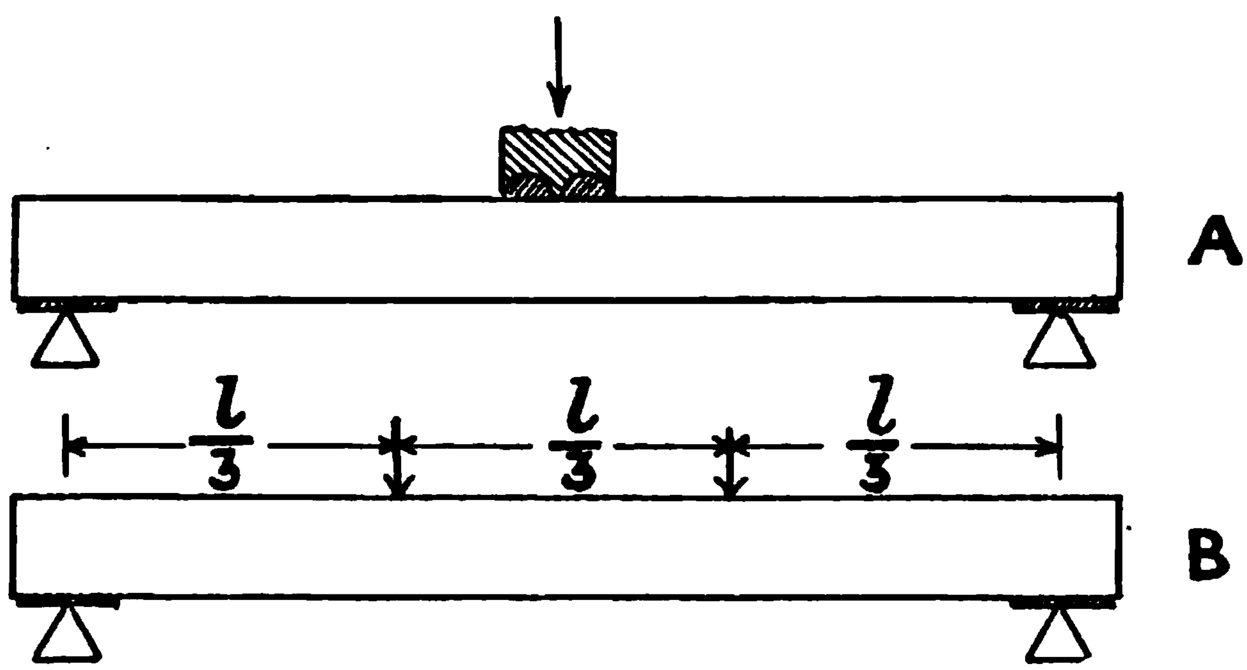



Fig. 81.

It is usual to make simultaneous readings during a test of vertical deflection and load, and for accurate results, in the case of beams of long span, the weight of the beam should be taken into account.

*Deflections* at the centre are measured in such a manner that compression of the wood at the points of support or loading does not introduce errors. One method of attaining this end (Fig. 82) is to drive two fine wire nails into the beam at the points of intersection of the neutral plane and the verticals through the supports, and to stretch a fine wire between the two nails, with a spring to keep the wire taut during the test. A vertical steel scale graduated to hundredths of an inch is fixed behind the wire upon the beam at its centre,

the attachment being made on the neutral plane. Deflections can be directly read off, or a reading telescope fixed at a convenient distance away may be employed for more accurate results. Fig. 84 illustrates another method* of measuring deflections, in which the cranked plate carrying the deflectometer lever rests upon two nails, one at each end on the neutral plane, vertically over the supports. A central neutral plane nail, as it deflects with the beam, works a 10 to 1 scale lever,

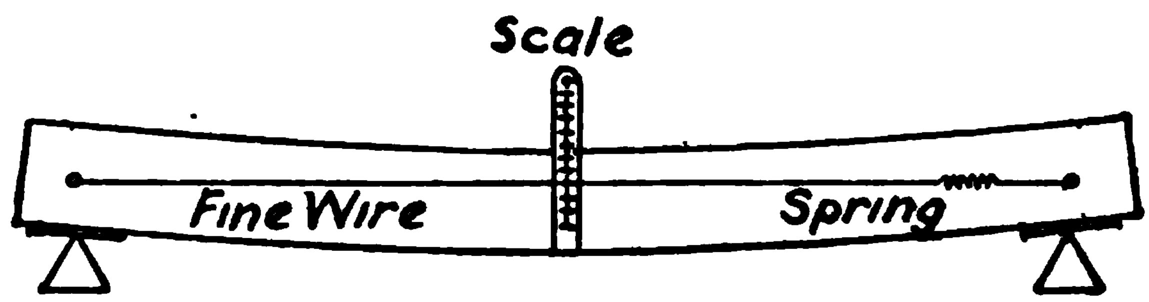



FIG. 82.

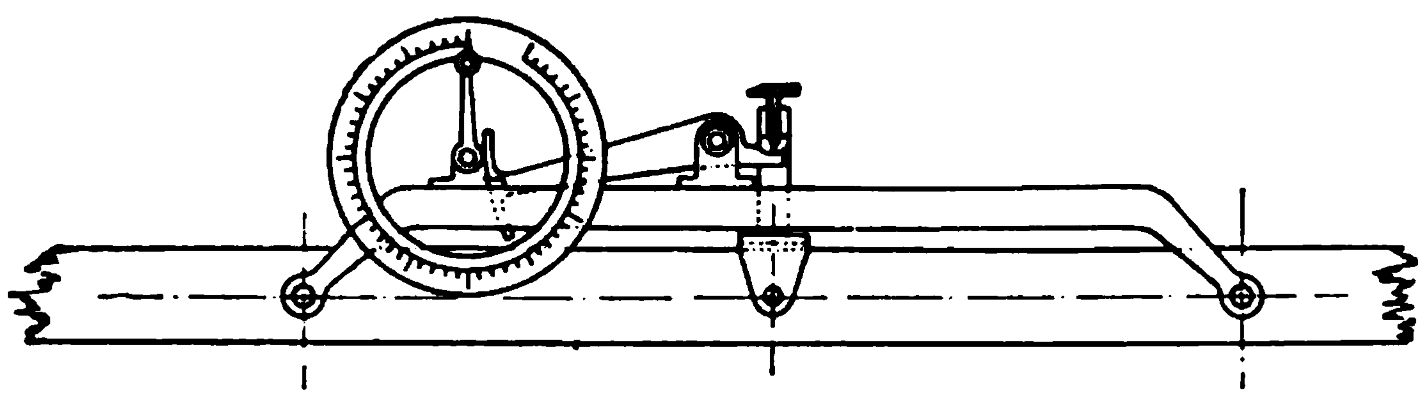


FIG. 83.—DEFLECTOMETER USED FOR ENGLISH OFFICIAL BEAM TESTS.

by means of a fine wire passing over an arc on the scale lever. A zero adjustment screw is provided.

The loads should not be applied in steps, with intervals between—that is to say, intermittently—but should be applied continuously at a specified rate.

Before the test is made notes should be taken of the direction of the grain at the ends, the average number of annual rings per inch, the proportion of late wood, the proportions of heartwood and sapwood, and sketches should be made of any grain irregularities, such as oblique or curly grain, the presence of knots, checks, splits, or shakes.

* Adopted by the U.S. Forestry Service.

Sketches should also be made of the manner of failure at the end of each test.

**Calculations.**—The following formulae are employed for

Fig. 84.

calculating the strength factors from the results of bending tests to rupture:

Notation:

$l$ = span in inches.

$b$ = breadth in inches.

$d$ = depth in inches.

D = deflection in inches at elastic limit.

$P_E$ = elastic limit load in pounds.

P = breaking load* in pounds.

W = weight of beam in pounds.

All values are given as pounds per square inch.

* P is here taken as being the added load, causing fracture.

*For Central Loading:* (A) (B)

| | (A) | (B) |
|---|---|---|
| Fibre stress at elastic limit | $=1{\cdot}5\,P_E \cdot \frac{l}{bd^2}$ | $1{\cdot}5(P_E+W)\cdot\frac{l}{bd^2}$ |
| Modulus of elasticity | $=\frac{0{\cdot}25\,P_E \cdot l^3}{bd^3 \cdot D}$ | $0{\cdot}25(P_E+W)\frac{l^3}{bd^3D}$ |
| Modulus of rupture | $=\frac{1{\cdot}5\,P \cdot l}{bd^2}$ | $\frac{1{\cdot}5(P+W)l}{bd^2}$ |
| Maximum shearing stress | $=\frac{0{\cdot}75\,P}{bd}$ | $\frac{0{\cdot}75(P+W)}{bd}$ |

*For Third-Point Loading:*

| | (A) | (B) |
|---|---|---|
| Fibre stress at elastic limit | $=\frac{P_E \cdot l}{bd^2}$ | $\frac{(P_E+W)l}{bd^2}$ |
| Modulus of elasticity | $=\frac{0{\cdot}213\,P_E \cdot l^3}{bd^3D}$ | $\frac{0{\cdot}213(P_E+W)l^3}{bd^3D}$ |
| Modulus of rupture | $=\frac{P \cdot l}{bd^2}$ | $\frac{(P+W)l}{bd^2}$ |
| Maximum shear stress | $=\frac{0{\cdot}75\,P}{bd}$ | $\frac{0{\cdot}75(P+W)}{bd}$ |

(A) denotes values neglecting weight of beam.

(B) denotes values taking weight of beam into account.

The work done, E, in bending the beam to the elastic limit or the elastic resilience, is given by :

$$E=\frac{0{\cdot}87\,P \cdot D}{2V},$$

where $V=lbd$, the volume of the beam.

In the case of large beams it is usual to add three-quarters of the beam's weight to the added load P, instead of the whole weight. The rate of load application, in terms of the speed of the moving head of the testing machine, expressed as inches per minute, is given by the following formula:*

$$r=\frac{z \cdot l^2}{6d},$$

where $z$=rate of fibre strain per inch of fibre length.

The values for $z$ generally taken are 0·0007 for large and 0·0015 for small beams.

* "The Effect of Speed of Testing," Proc. Amer. Soc. for Testing Materials, vol. viii., 1908.

TABLE XCIV.

RESULTS OF TRANSVERSE BENDING TESTS UPON BEAMS.

The dimensions of the beams were: 24 inches span × 2 inches deep × 1 inch wide.)

| *Material.* | *Central Breaking Load, in Pounds.* | *Modulus of Rupture, Pounds per Square Inch.* |
|---|---|---|
| Ash .. .. .. .. | 1358 | 12,250 |
| Ash .. .. .. .. | 1340 | 12,100 |
| Ash .. .. .. .. | 1392 | 12,550 |
| Spruce .. .. .. | 952 | 8330 |
| Spruce .. .. .. | 933 | 8190 |
| Spruce .. .. .. | 952 | 8330 |
| Walnut (English) .. .. | 1575 | 14,800 |
| Walnut (English) .. .. | 1774 | 16,000 |
| Walnut (English) .. .. | 1509 | 13,640 |

*Note.*—In all cases the beams failed by tension on the lower sides, accompanied by longitudinal cracks. Partial yielding also occurred by direct shearing at the places of loading and support, this effect being most marked in the case of the spruce or softwood beam. The ash showed the greatest deflection for its breaking load.

## Results of Bending Tests.

The four important strength properties of beams that it is usually desirable to investigate are—(1) The Fibre Stress at the extreme surface from the neutral plane, at the elastic limit; (2) the Modulus of Elasticity; (3) the Bending Coefficient, Modulus of Rupture, or fibre stress at the breaking-point; and (4) the work done in bending to the elastic limit or maximum load. From observations of loads and corresponding deflections, and knowing the dimensions of the beams, these four strength values are directly calculable from the preceding formulae.

In Tables Nos. XCIV to XCVIII the results of a number of different series of typical bending tests, carried out in England, America, and Germany, are given, together with information as to the size, moisture condition, and other factors, where known.

## TABLE XCV.

### RESULTS OF TRANSVERSE BENDING TESTS (LANZA).*

(Dimensions of Beams from 4 to 20 feet span × from 2 to 12 inches deep × from 2 to 6 inches wide.)

| *Material.* | | *Coefficient of Bending Strength, or Modulus of Rupture, Pounds per Square Inch.* | *Modulus of Elasticity, Pounds per Square Inch.* |
|---|---|---|---|
| Spruce .. .. .. | Maximum | 8750 | 1,590,000 |
| | Minimum | 2950 | 896,000 |
| | Mean | 4880 | 1,331,000 |
| White pine .. .. | Maximum | 7250 | 1,281,000 |
| | Minimum | 3440 | 925,000 |
| | Mean | 4810 | 1,085,000 |
| Yellow pine .. .. | Maximum | 10,380 | 2,380,000 |
| | Minimum | 3960 | 1,165,000 |
| | Mean | 7290 | 1,743,000 |
| Oak .. .. .. | Maximum | 7650 | 1,768,000 |
| | Minimum | 4980 | 853,000 |
| | Mean | 6075 | 1,292,000 |

## TABLE XCVI.

### RESULTS OF TRANSVERSE BENDING TESTS UPON BEAMS. (Bauschinger.)†

(Dimensions of beams: 98 inches span × 7½ inches × 7½ inches. The moisture content varied from 23 to 34 per cent.)

| *Material and Locality.* | *Modulus of Elasticity, Pounds per Square Inch × 10⁶.* | | *Elastic Limit, Pounds per Square Inch.* | | *Modulus of Rupture, Pounds per Square Inch.* | | *Specific Gravity (Mean).* |
|---|---|---|---|---|---|---|---|
| | Summer-Felled. | Winter-Felled. | Summer-Felled. | Winter-Felled. | Summer-Felled. | Winter-Felled. | |
| Red pine (Lichtenhoff) | 1·540 | 1·468 | 2870 | 3135 | 6720 | 6400 | 0·525 |
| Spruce (Frankenhoffen) | 1·567 | 1·650 | 3245 | 3718 | 5960 | 6410 | 0·45 |
| Spruce (Regenhütte) | 1·637 | 1·567 | 3340 | 3225 | 5920 | 6340 | 0·445 |
| Spruce (Schliersee) | 1·040 | 0·982 | 2085 | 1880 | 4190 | 3660 | 0·365 |

* Summary of Lanza's tests, by Unwin, "Materials of Construction," p. 407.

† "Mittheilungen aus dem Mech. Techn. Labor. in München," 1883-1887. Also *vide* Unwin, "Materials of Construction," p. 405.

In the spruce and yellow pine beam-bending tests, failure often occurred by longitudinal shearing along or near the neutral axis. The mean intensity of this failing shear stress worked out at 191 pounds per square inch in the case of the spruce beams, and 248 pounds per square inch for the yellow pine beams.

It was found that the greatest bending strength, in the case of hickory, occurred when the number of annual rings per inch was between 5 and 20; the modulus of elasticity varied from 1,000,000 to 1,400,000 pounds per square inch, and the density from 46 to 52 pounds per cubic foot.

TABLE XCVII.

RESULTS OF TRANSVERSE BENDING TESTS UPON HICKORY BEAMS.*

| *Species.* | | *Percentage Moisture.* | *Specific Gravity.* | *Modulus of Rupture, Pounds per Square Inch.* | *Work in Bending to Maximum Load, Inch-Pounds per Cubic Inch.* |
|---|---|---|---|---|---|
| Pignut | Average | 9·5 | 0·776 | 23,482 | 31·2 |
| | High 10% | 10·3 | 0·862 | 27,804 | 52·5 |
| | Low 10% | 8·6 | 0·648 | 16,563 | 13·2 |
| Shagbark | Average | 9·7 | 0·742 | 22,148 | 27·8 |
| | High 10% | 10·5 | 0·811 | 26,760 | 47·8 |
| | Low 10% | 9·2 | 0·666 | 17,953 | 11·7 |
| Mockernut | Average | 9·3 | 0·723 | 20,370 | 22·1 |
| | High 10% | 11·2 | 0·821 | 25,120 | 37·8 |
| | Low 10% | 8·2 | 0·666 | 15,370 | 9·6 |
| Big shellbark | Average | 9·3 | 0·736 | 19,724 | 23·6 |
| | High 10% | 10·4 | 0·801 | 25,320 | 38·2 |
| | Low 10% | 8·4 | 0·627 | 16,070 | 6·2 |

Two principal features of the results given in Table XCVIII. are: (1) That the fibre stress at the elastic limit is greatest for the 2-inch square specimens of the different timbers; and (2) that the modulus of rupture is always greatest for the 2-inch square specimens. The latter result is to be expected

* U.S. Forestry Service Bulletin, No. 80 (1910).

# TABLE XCVIII.

## Results of Bending Tests on Air-Seasoned Timber Beams.

Average values from U.S. Forestry Service Tests (Record).

| Material. | Dimensions in Inches. Span. | Width. | Depth. | Percentage of Moisture. | Number of Rings per Inch. | Fibre Stress at Elastic Limit, Pounds per Square Inch. | Modulus of Rupture, Pounds per Square Inch. | Modulus of Elasticity, Pounds per Square Inch. | Estimated Shearing Stress, Pounds per Square Inch. |
|---|---|---|---|---|---|---|---|---|---|
| Longleaf pine .. .. | 180 | 16 | 8 | 22·2 | 16·0 | 3390 | 4274 | 1,747,000 | 288 |
| ,, ,, .. .. | 177 | 8 | 6 | 20·0 | 13·7 | 4227 | 8196 | 1,634,000 | 177 |
| ,, ,, .. .. | 30 | 2 | 2 | 15·9 | 13·9 | 6750 | 11,520 | 1,740,000 | 383 |
| Douglas fir .. .. .. | 180 | 16 | 8 | 20·8 | 13·1 | 4563 | 6372 | 1,549,000 | 269 |
| ,, ,, .. .. .. | 180 | 8 | 5 | 14·9 | 12·2 | 5065 | 6777 | 1,853,000 | 218 |
| ,, ,, .. .. .. | 24 | 2 | 2 | 19·0 | 16·4 | 6686 | 10,378 | 1,695,000 | 419 |
| Shortleaf pine .. .. | 180 | 16 | 8 | 17·0 | 12·3 | 4220 | 6030 | 1,517,000 | 398 |
| ,, ,, .. .. | 180 | 8 | 5 | 12·2 | 22·5 | 7123 | 9373 | 1,985,000 | 301 |
| ,, ,, .. .. | 30 | 2 | 2 | 14·2 | 13·7 | 7780 | 12,120 | 1,792,000 | 404 |
| Western larch .. .. | 180 | 16 | 8 | 18·3 | 21·9 | 3343 | 5440 | 1,409,000 | 349 |
| ,, ,, .. .. | 180 | 8 | 5 | 13·6 | 27·6 | 4730 | 7258 | 1,620,000 | 221 |
| ,, ,, .. .. | 30 | 2 | 2 | 16·1 | 26·8 | 5880 | 10,254 | 1,564,000 | 364 |
| Loblolly pine .. .. | 180 | 16 | 8 | 20·5 | 7·4 | 4195 | 6734 | 1,619,000 | 462 |
| ,, ,, .. .. | 132 | 8 | 4 | 19·5 | 9·1 | 3384 | 6194 | 1,200,000 | 196 |
| ,, ,, .. .. | 30 | 2 | 2 | 17·6 | 6·6 | 5170 | 9400 | 1,467,000 | 318 |
| Tamarack .. .. .. | 162 | 12 | 6 | 23·0 | 15·1 | 3434 | 5640 | 1,330,000 | 318 |
| ,, .. .. .. | 162 | 10 | 4 | 14·4 | 9·7 | 4100 | 5320 | 1,356,000 | 252 |
| ,, .. .. .. | 30 | 2 | 2 | 11·3 | 16·2 | 7630 | 13,080 | 1,620,000 | 425 |
| Western hemlock .. .. | 180 | 16 | 8 | 17·7 | 17·8 | 4398 | 6420 | 1,737,000 | 406 |
| ,, ,, .. .. | 28 | 2 | 2 | 17·9 | 19·4 | 6333 | 10,369 | 1,666,000 | 382 |
| ,, ,, .. .. | | | | | | | | | |
| Redwood .. .. .. | 180 | 16 | 8 | 26·3 | 22·4 | 3797 | 4428 | 1,107,000 | 294 |
| ,, .. .. .. | 180 | 9 | 7 | 15·9 | 15·2 | 3280 | 4002 | 1,104,000 | 147 |
| ,, .. .. .. | 28 | 2 | 2 | 15·2 | 18·8 | 4777 | 7798 | 1,146,000 | 279 |
| Norway pine .. .. | 162 | 12 | 6 | 16·7 | 8·1 | 2968 | 5204 | 1,123,000 | 286 |
| ,, ,, .. .. | 162 | 10 | 4 | 13·7 | 12·0 | 5170 | 6904 | 1,712,000 | 317 |
| ,, ,, .. .. | 30 | 2 | 2 | 14·1 | 11·2 | 5280 | 8470 | 1,158,000 | 281 |

from the theoretical considerations of the formula for this modulus, viz. :

$$f = \frac{1 \cdot 5\, Pl}{b \cdot d^2}.$$

The value of the product $b \cdot d^2$ for a given rectangular area is least for the square section, and therefore, for the same load and span, the modulus $f$ is greater.

All comparisons of moduli of rupture should be made upon specimens either of the same dimensions or of the same proportions.

The value of the equivalent fibre stress at the breaking value of the bending moment, as given by the relation upon p. 283, depends to some extent upon the shape and dimensions of the beam sections. If M is the equivalent B.M. estimated from the relation,

$$M = f_t \cdot Z,$$

where $f_t$ = the static tensile strength, $Z$ = the strength modulus of the section, then the actual value of the breaking B.M.—namely, $M^1$—will also depend upon the shape and dimensions of the section, and is usually greater than M. The ratio $\frac{M^1}{M}$ is greatest for a circular section, and least for a channel or deep rectangular form. The following values are given by Lineham* for this ratio for rectangular sections—namely: Oak, 0·7 to 1·0; pitch pine, 0·8 to 2·2; fir, 0·52 to 0·94. For metals the ratio is invariably greater than unity.

## The Stiffness of Beams.

A beam is said to be " stiff " when it will support a relatively high value of load with a small deflection. For a given span and cross-section, the stiffness of a beam is directly proportional to the load, and inversely to the deflection caused by the load. For different beams the stiffness varies as the

* " Mechanical Engineering."

breadth, as the cube of the depth, and inversely as the span squared.

For a beam of span L feet supported at the ends and loaded at the centre with W pounds, the following relation holds:

$$a=\frac{WL^2}{BD^3},$$

where B = breadth in inches, D = depth in inches, and $a$ is a constant, depending upon the timber.

Tredgold gives the following values for $a$: Fir, 0·01; ash, 0·01; beech, 0·013; teak, 0·008; mahogany, 0·02; elm, 0·015; oak, 0·013.

## Breaking Strength and Deflection of Beams.

The results of experiments upon the fracture of wooden beams may be expressed in the following form—viz.:

$$W=c\frac{bd^2}{l},$$

where W = breaking load in pounds, $b$ = breadth, $d$ = depth, and $l$ = the length or span, all in inches, and $c$ = a constant.

Similarly, the deflection* may be expressed by the relation—

$$d=\frac{k\cdot W_o\cdot l^3}{b\cdot d^3},$$

where $W_o$ = the load upon beam causing deflection, $k$ = a constant.

For beams supported at the ends and loaded at the middle the constants $c$ and $k$ have the values shown in table XCIX.

The breaking loads and deflections of other types of beams under different systems of loadings may be deduced from the results given for the beam supported at the ends and loaded at the centre.

If $W_1$ be the breaking load of a beam loaded in any other manner, then, using the same notation as before,

$$W_1=n\cdot W,$$

where $n$ is a constant for each type of loading and support.

* The deflection up to the elastic limit.

Similarly, the deflection within the elastic limit is given by $d_1 = m \cdot d$. The values of $n$ and $m$ for certain typical cases are given in table C.

TABLE XCIX.

CONSTANTS IN BREAKING AND DEFLECTION FORMULAE.*

| *Material.* | *Value of* c *for Breaking Load.* | *Value of* k *for Deflection.* |
|---|---|---|
| Teak .. .. .. .. | 820 | 0·00018 |
| Oak .. .. .. .. | 450–600 | 0·00044–0·00020 |
| English oak .. .. .. | 557 | 0·0003 |
| Ash .. .. .. .. | 675 | 0·00026 |
| Beech .. .. .. .. | 518 | 0·00031 |
| Pitch pine .. .. .. | 544 | 0·00035 |
| Red pine .. .. .. | 450 | 0·00023 |
| Fir .. .. .. .. | 370 | 0·0005–0·0002 |
| Larch .. .. .. .. | 284 | 0·00041 |
| Deal .. .. .. .. | 600 | 0·00023 |
| Elm .. .. .. .. | 337 | 0·00061 |

TABLE C.

VALUES OF CONSTANTS M AND N.

| *Manner of Loading and Support.* | n. | m. |
|---|---|---|
| Beam loaded at centre; supported at ends .. | 1 | 1 |
| Beam loaded uniformly; supported at ends .. | 2 | 0·625 |
| Beam loaded uniformly; fixed rigidly at ends (encastré) | 3 | 0·125 |
| Beam loaded at centre; fixed rigidly at ends (encastré) | 2 | 0·250 |
| Beam loaded at one end; fixed at other end (cantilever) | 0·25 | 16·0 |
| Beam loaded uniformly; fixed at other end (cantilever) | 0·50 | 6 |

*Note.*—In all cases the span or length is equal to $l$ inches, and the results are referred to the case of the beam supported at the ends and loaded at the centre.

## Manner of Failure of Beams.

The manner in which a given beam of timber will fail in bending is dependent upon the kind of timber, its degree of

* "Applied Mechanics," by Professor Perry.

moisture, manner of loading, arrangement of the grain, and upon the proportions of the beam.

Some timber, such as white cedar, is more brittle than

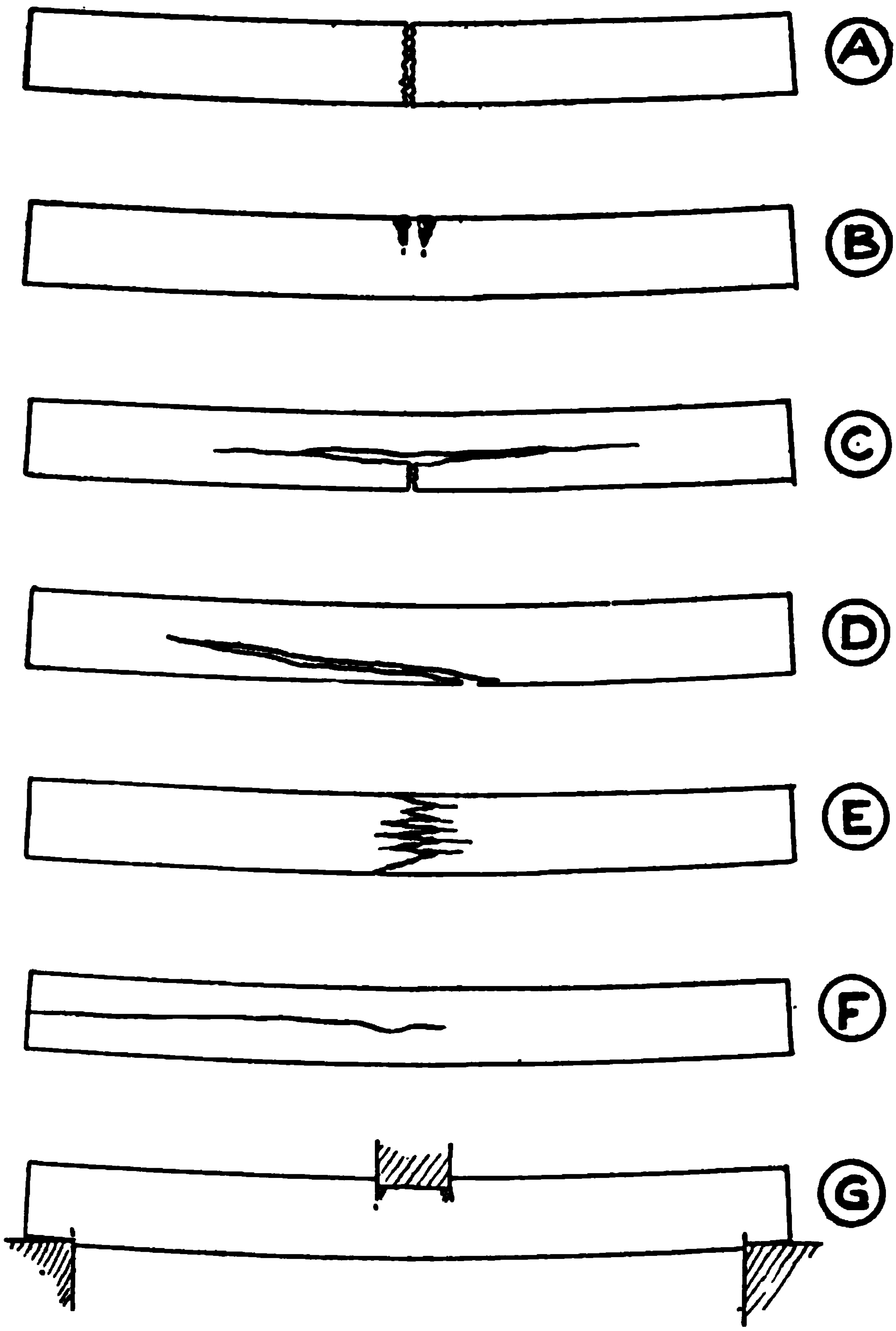



FIG. 85.—SHOWING MANNERS OF FAILURE OF BEAMS.

others, and invariably fails by breaking clean through, probably beginning upon the tension side, as shown in Fig. 85, *A*.

Wet or green timber generally fails by compression, owing

to the effect of moisture reducing the compressive strength to a much greater degree than the tensile strength. Compression failures are apparent by a crinkling or buckling of the fibres on the uppermost side as shown in Fig. 85, *B*, when the elastic limit is exceeded. This effect often spreads towards the neutral axis.

The type of failure most frequently met with is the tension one, in which the lowermost fibres break first and the tearing then extends upwards, as shown in Fig. 85, Diagrams *C*, *D*, and *E*, of which *C* represents the normal type of fracture met with in straight-grained hardwoods such as ash, birch, or walnut, *D* represents a cross-grained tensile fracture due to obliquity or want of straightness of grain, whilst the jagged type of fracture shown in *E* is usually obtained with tough fibrous woods, such as oak, hickory, and similar woods.

Failure often occurs by horizontal shearing along the neutral axis, by a relative sliding action of the two halves, as shown in Fig. 85, Diagram *F*. It will be readily seen, from the considerations dealt with on p. 283, that for a given span, cross-section, area, and loading, the greatest intensity of horizontal shearing force will occur for beams in which the depth-width ratio is high, and the practical results confirm this. The horizontal shear, as has been shown,* is always accompanied by an equal vertical shear, but as the cross-fibre shearing strength is much greater than the shearing strength along the fibres, the failure occurs in the latter sense. The presence of defects such as shakes or seasoning checks reduces the resistance to shear, so that beams having any such defect, near the neutral axis often fail in this manner.

In the case of softwood beams, such as spruce, pine, or larchs the shearing strength along the grain is a smaller percentage of the compressive or tensile strength than in the case of hardwoods, so that failures by shear are a common occurrence.

Direct shear failure at the supports or points of load application are also apt to occur, as shown in Fig. 85, Diagram *G*,

* See Chapter I, Vol. I, of this work.

for deep softwood beams of small width; plates should be provided at these places in order to distribute the loads.

## Compressive Strength of Timber.

**Short Specimens.**—The compressive strength along the grain is only from about $\frac{1}{4}$ to $\frac{1}{2}$ of the tensile strength for the majority of straight-grained timbers, and the ratio of the compressive strengths along and across the grains varies from about $\frac{1}{5}$ to $\frac{1}{6}$.

When a short block of timber is compressed across the grain, the wood fibres, which are separated by air chambers, interstices, or cells, tend to bunch together, thereby increasing the density; ultimate failure is then by simple crushing of the wood material. If, however, the load is applied over a plate smaller than the surface of the block, failure by shearing occurs. Failure across the grain is analogous to the breakdown of the cohesion of a bunch of longitudinal rods or fibres loaded crosswise. When short blocks are tested in compression along the grain, failure usually occurs by shearing along a plane at between 45° and 55° to the axis; there are however, several types of fracture, depending upon the species of timber and proportions of the test block.

One common type of failure for certain hardwoods, or for green or wet timber, is that illustrated in Fig. 86, in which the fibres tend to split up and to fail by bending or buckling; the preliminary lateral swelling tends to separate the fibres, after which failure by buckling or bending takes place.

There is no true type of failure for each species of timber, and several alternative types often occur in timber from different parts of the same tree.

Fig. 87 shows the dimensions and shape of the Air Ministry standard compression test piece for silver spruce, whilst the inset diagram on the right illustrates the method adopted for ensuring a truly axial load; it will be seen that balls are inserted at the two ends, between two hardened steel surfaces.

Fig. 86.—Compression Failure of Timber.

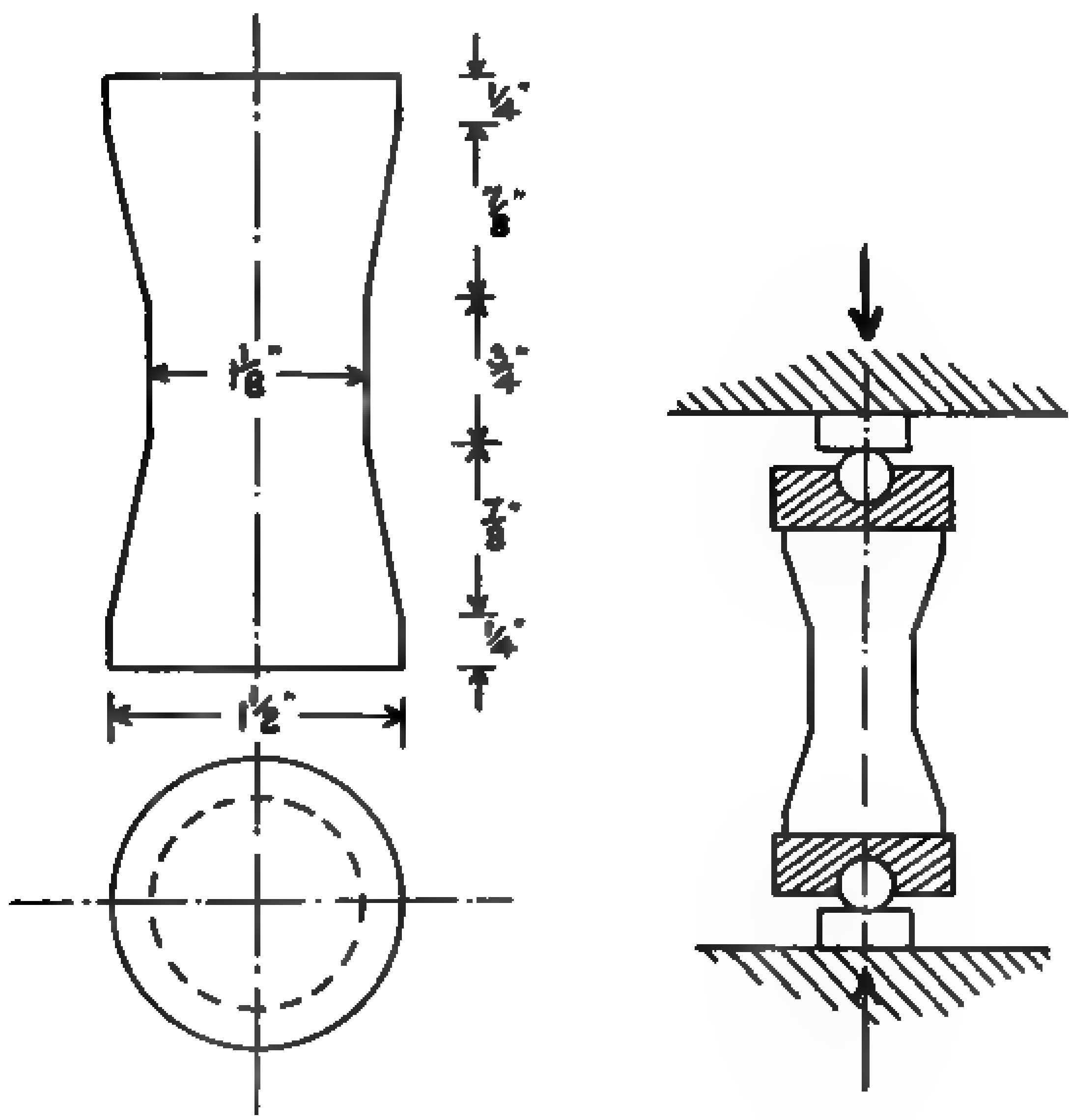



Fig. 87.—Shape of Test Specimen for Compression Tests.

## TABLE CI.

COMPRESSIVE STRENGTHS ALONG AND ACROSS THE GRAIN.
(U.S. Forestry Service.)

*(A) Green Material.*

| *Material.* | *Compression along Grain.* | | | | *Compression Perpendicular to Grain.* | |
|---|---|---|---|---|---|---|
| | *Percentage of Moisture* | *Stress at Elastic Limit.** | *Modulus of Elasticity.** | *Crushing Stress.** | *Percentage of Moisture.* | *Crushing Stress.†* |
| Longleaf pine .. | 26·3 | 3480 | — | 4800 | 25·3 | 568 |
| Douglas fir .. | 30·9 | 2720 | 2123 | 3490 | 33·7 | 368 |
| Shortleaf pine .. | 41·2 | 2514 | 1565 | 3436 | 37·7 | 361 |
| Western larch .. | 49·1 | 2675 | 1575 | 3510 | 43·6 | 417 |
| Loblolly pine .. | 63·4 | 1560 | 365 | 2140 | 67·2 | 392 |
| Tamarack .. | 49·9 | 2332 | 1432 | 3032 | — | — |
| Western hemlock | 46·6 | 2905 | 1617 | 3355 | 48·7 | 434 |
| Redwood .. | 83·6 | 3194 | 1240 | 3882 | 86·7 | 473 |
| Norway pine .. | 29·0 | 1928 | 905 | 2404 | — | — |
| White spruce .. | 61·0 | — | — | 2370 | 50·4 | 270 |

*(B) Air-Seasoned Material.*

| | | | | | | |
|---|---|---|---|---|---|---|
| Longleaf pine .. | 26·3 | 3480 | — | 4800 | 25·1 | 572 |
| Douglas fir .. | 20·3 | 3271 | 1038 | 4258 | 20·8 | 732 |
| Shortleaf pine .. | 15·7 | 4070 | 1951 | 6030 | 17·8 | 725 |
| Western larch .. | 16·0 | — | — | 5445 | 18·8 | 491 |
| Loblolly pine .. | 22·4 | 2217 | 545 | 2950 | 22·9 | 679 |
| Tamarack .. | 15·7 | 2257 | 1042 | 3323 | 16·2 | 697 |
| Western hemlock | 18·6 | 4840 | 2140 | 5814 | 18·2 | 514 |
| Redwood .. | 16·8 | — | — | 4276 | 14·7 | 610 |
| Norway pine .. | 15·2 | 2670 | 1182 | 4212 | 10·0 | 924 |

*Note.*—The above results refer to short specimens of cross-section about 6×6 inches.

It has been found that the crushing test upon short specimens gives more uniform results than bending or tensile tests, except as regards the elastic modulus value, and, moreover, it is more easy to perform.

* Pounds per square inch × 1000.
† Pounds per square inch.

The results of Bauschinger's* tests upon pine and spruce specimens show that compressive strength increases with the density of the timber, and also with the dryness. It was also found that the timber of winter felling (tested three month after cutting down) was about 25 per cent. stronger than summer-felled wood, but if both were seasoned for a long period (one to three years) the differences in strength were very small. The strength of pine wood† is expressible by the following relation:

$$f_c = 6{\cdot}35d - 0{\cdot}635,$$

where $f_c$=the compressive strength in tons per square inch, and $d$= the density at 15 per cent. dryness.

There is an approximate relation, for the same species of wood, between the compressive strength along the grain and the density, as follows:

$$f_c = w \cdot 165,$$

where $f_c$=compressive stress in pounds per square inch $w$=weight in pounds per cubic foot.

It has also been found that there is a fairly definite relation between the compressive strength along the grain and the extreme fibre stress at the elastic limit in bending, the latter stress being from 6 to 12 per cent. higher upon the average.

Values for the compressive strengths of typical English and foreign timbers will be found in Table CVIII, whilst Table CI, shows the results of tests made at the instance of the U.S. Forestry Service authorities upon both green and air-seasoned materials for directions along and perpendicular to the grain.

## Strength of Long Struts.

The properties of timber struts when the slenderness ratio exceeds about 5 or 10 closely resemble those of the long metal columns under end load, discussed in Vol. I. of this work.

* See p. 264.

† For the strength of spruce of different densities see Fig. 78, and p. 268.

The individual results of timber strut tests, however, vary considerably among themselves, the variations in the crippling loads often varying by as much as 50 per cent.; this discrepancy in the results is due to the fact that the strength of timber is dependent upon a number of factors, such as its fibre or internal structure, rate and mode of growth, moisture content or seasoning, and other quantities, as explained in the earlier part of this chapter.

Long struts usually fail by excessive side-bending and fracture, somewhat similar to the cases of beams, except that there is superimposed a compressional effect.

The strength of timber struts may be expressed by a formula of the Rankine-Gordon type, as follows—namely:

$$\text{Crippling stress } p = \frac{f_c}{1 + c \cdot \frac{l^2}{k^2}},$$

where the $l/k$ is the ratio of the length of radius of gyration. For oak and pine, hinged or rounded columns, the values usually taken for the constants are as follows—

$$f_c = 8000 \text{ pounds per square inch, } c = \tfrac{1}{3000}.$$

For selected ash and French walnut, $f_c = 6500$ pounds per square inch, and $c = \frac{1}{3000}$.

For silver spruce of the better selected grade and lower grade ash, $f_c = 5000$ pounds per square inch, and $c = \frac{1}{3000}$.

A formula often used in aeroplane practice for ash and spruce longeron struts and similar purposes is—

$$\text{Crippling stress } p = \frac{4000}{1 + \frac{1}{3750}\left(\frac{l}{k}\right)^2}.$$

Fig. 88 gives the values of hinged struts for the materials indicated, as estimated from the above Rankine-Gordon type of formula.

When the ends of the strut are rigidly fixed both in position and direction, the strut is, of course, stronger; in the preceding formulae the value of the constant $c$ must in this case be divided by 4.

A number of tests were made a few years ago at the Royal Aircraft establishment upon pin-jointed ash and spruce struts, the results of which were found to be conveniently expressed by the formula—

$$p=\frac{f_c}{1+a\cdot\frac{l^2}{k^2}},$$

$f_c=5600$ pounds per square inch for spruce,
$f_c=6250$ pounds per square inch for ash.

where the value of the quantity $a$ varies with the slenderness ratio $\left(\frac{l}{k}\right)$ in the manner shown in Fig. 89.

The units employed in the above formulae are inches and pounds, the other symbols having the same meaning as before.

An interesting series of experiments upon hinged spruce struts of carefully selected material were made at the Massachusetts Institute of Technology in 1915. The results of the tests showed that for values of $\left(\frac{l}{k}\right)$ less than 70 the breaking stress was related to the slenderness ratio $\left(\frac{l}{k}\right)$ by a direct or straight-line formula, as follows:

$$p=\frac{P}{A}=6500-46{\cdot}5\left(\frac{l}{k}\right).$$

P = total breaking load in pounds,
A = strut area in square inches.

When the ratio $\left(\frac{l}{k}\right)$ was greater than 70, the breaking stress was found to vary inversely as the square of the slenderness ratio, and directly as the modulus of elasticity (bending); thus—

$$p=\frac{P}{A}=\frac{8{\cdot}72\,E}{\left(\frac{l}{k}\right)^2}.$$

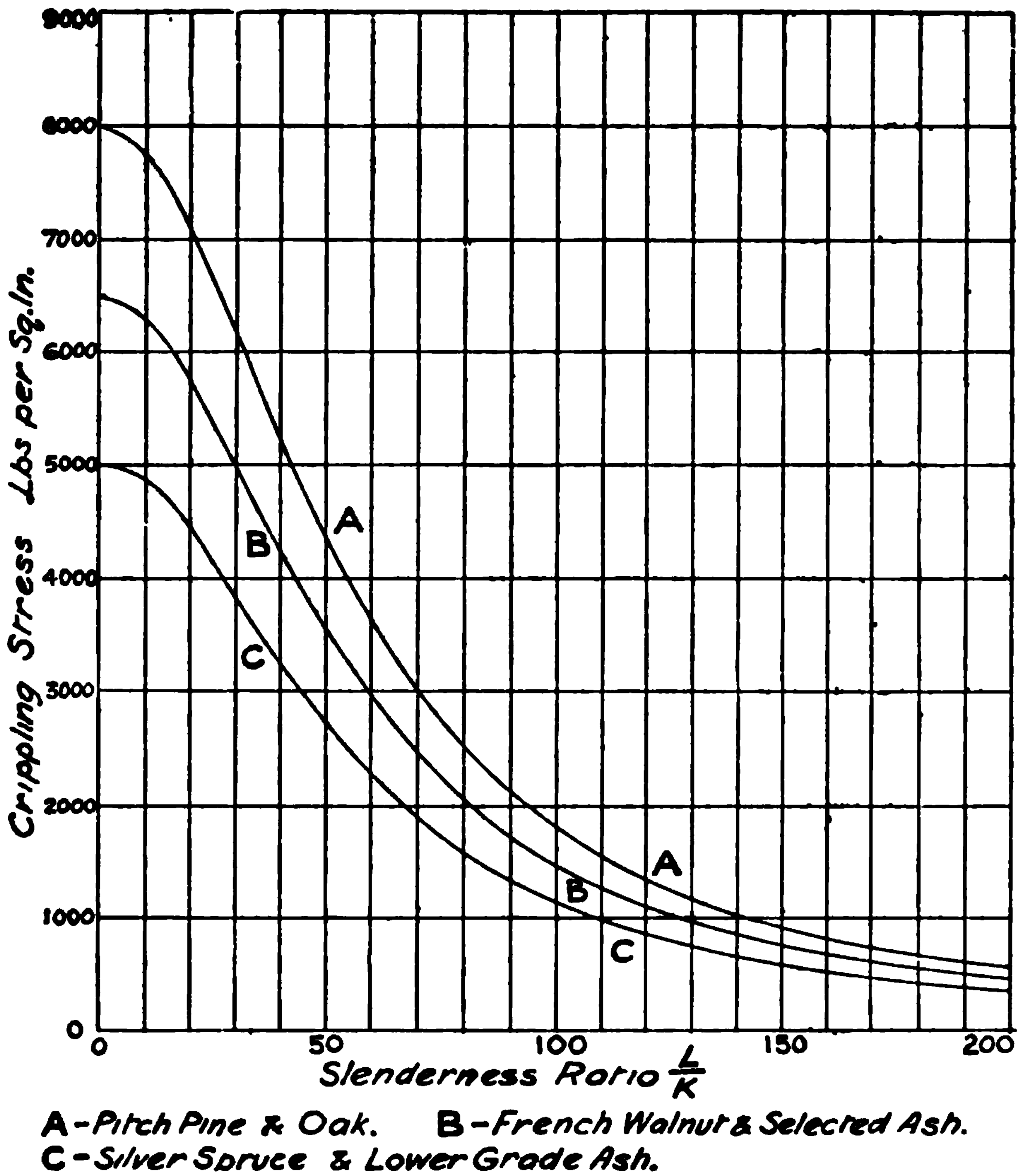

9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Crippling Stress Lbs per Sq. In.
0
50
100
150
200
Slenderness Ratio $\frac{L}{K}$
A
B
C
A
B
C
A - Pitch Pine & Oak.
B - French Walnut & Selected Ash.
C - Silver Spruce & Lower Grade Ash.

FIG. 88.

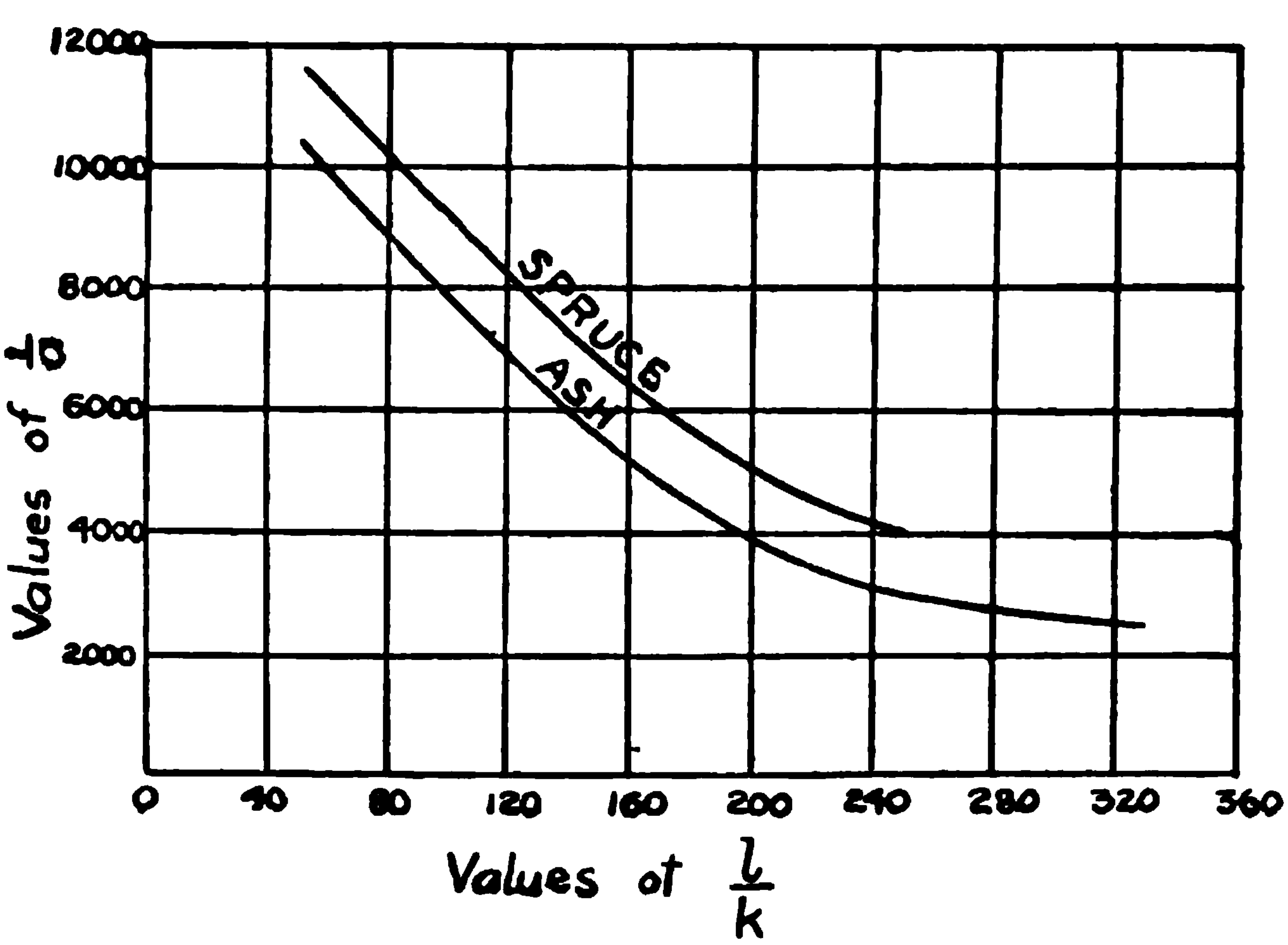

12000
10000
8000
6000
4000
2000
Values of $\frac{1}{\phi}$
0
40
80
120
160
200
240
280
320
360
Values of $\frac{l}{k}$
SPRUCE
ASH

FIG. 89.

The average value found for E was 1,825,000 pounds per square inch. This formula is similar to Euler's for long struts.

The factor of safety for aircraft work was recommended to lie between 8 and 16.

It was found that the strength of tapered struts was less than that of parallel struts of the same maximum cross-section, although there is no doubt that the strength to weight ratio is higher for tapered struts.

The ideal aeroplane strut is the hollow high-tensile steel tapered tubing type, or the built-up hollow tapered streamline wooden one.*

Struts which are loaded out of centre or are subjected to a side-bending effect have their strength appreciably diminished.

**Aeroplane Struts.**

Owing to the necessity of low weight in the case of aircraft members, it is necessary to be able to calculate the strength of struts accurately, so that no unnecessary surplus weight need be carried.

It is usual to calculate the strength from formulae based upon full-sized breaking-test results. The struts are always tapered in section from the centre to the ends, so as to approximate to the condition of equal strength throughout the length.

All aeroplane struts are hinged about an axis perpendicular to the streamline major axis, and they are streamlined. The best forms of strut section are similar to those shown in Fig. 90, and these possess the property of least head resistance for minimum weight and maximum strut strength.

Table CII, page 302, illustrates the principal properties of typical sections.

It will be seen that the best aeroplane strut section is the Beta, and the next best the Baby, these sections being derived from dirigible shapes.

If wind resistance does not enter into the considerations, as in the case of unexposed members, then the circular section is the best; the circular tube is, however, much stronger than the solid rod of the same weight.

* See also p. 537 *et seq.*

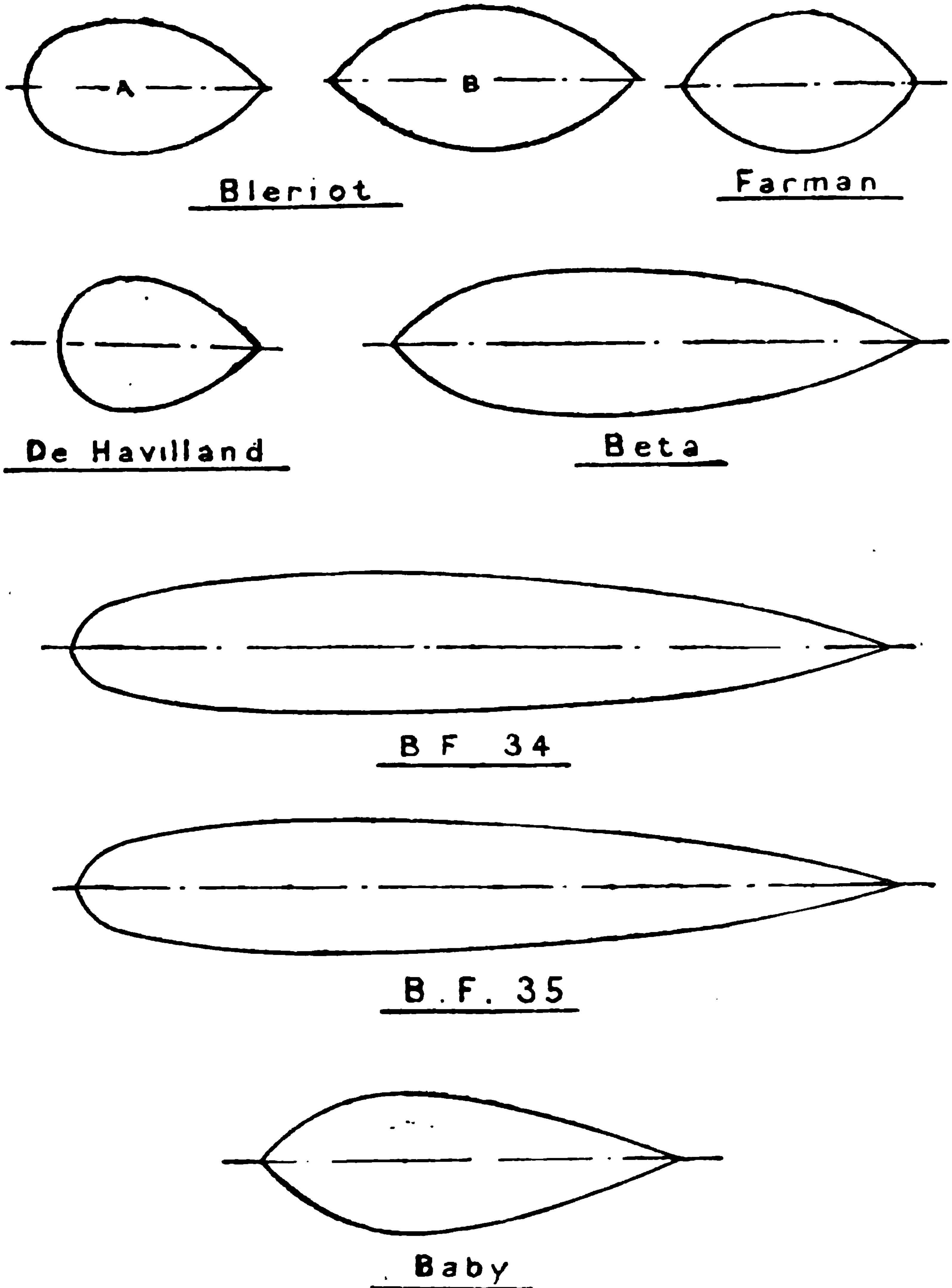



Fig 90.

TABLE CII.

PROPERTIES OF AEROPLANE STRUT SECTIONS.

| *Name of Section.* | *Wind Resistance per 100 Feet Length, at 60 Feet per Second, in Pounds per 1 Inch Minimum Width.* | *Weight per 100 Feet Length, per 1 Inch Minimum Width, in Pounds.* | *Relative Merit Number for Suitability for Aeroplane Exposed Strut.* |
|---|---|---|---|
| Circle 1 inch diameter | 43·0 | 23·4 | 1017 |
| Ellipse 2 inch×1 inch | 22·0 | 46·8 | 628 |
| Ellipse 5 inch×1 inch | 15·2 | 117·0 | 539 |
| De Havilland .. | 25·0 | 29·2 | 720 |
| De Havilland (reversed) | 22·6 | 29·2 | 640 |
| Farman .. .. | 22·9 | 36·0 | 609 |
| Bleriot A .. .. | 23·7 | 37·2 | 685 |
| Bleriot B .. .. | 24·5 | 49·8 | 695 |
| Baby .. .. | 7·9 | 59·4 | 261 |
| Beta .. .. .. | 6·9 | 88·1 | 225 |
| B.F. 34 .. .. | 7·2 | 133·0 | 267 |
| B.F. 35 .. .. | 6·3 | 128·0 | 249 |

*Note.*—The most suitable aeroplane strut section is the one giving the lowest value in the last column—that is, having the lowest weight by resistance product for struts of equal strength.

## Shearing Strength of Timber.

Timber is often called upon to resist shearing action, and a knowledge of the shearing-strength properties therefore becomes essential.

The direction of greatest shearing strength is across the grain perpendicular to the fibres, and that of least strength is along the grain; the ratio of these two stresses varies from 5 to 8 in the case of hardwoods, such as ash, beech, birch, hickory, or oak, and from 3 to 6 for softwoods, such as pines, poplar, spruce, or firs. The shearing strength across the grain is closely related to the compressive strength in this direction, and also to the hardness; in many cases there is an approximate equality, other conditions being the same, between the shearing and compressive strengths across the grain.

Short columns of timber under compressive load often fail

by oblique shearing action, the plane of shear being inclined at an angle varying from 45° to 55° to the axis of loading.

The strength in shear along the grain is very low in most straight-grained timbers, but is higher in curly or wavy grained specimens.

The shearing strength along the grain is from 1½ to 2 times the tensile strength across the grain


FIG. 91. — SHEARING TEST ARRANGEMENT FOR TIMBER.

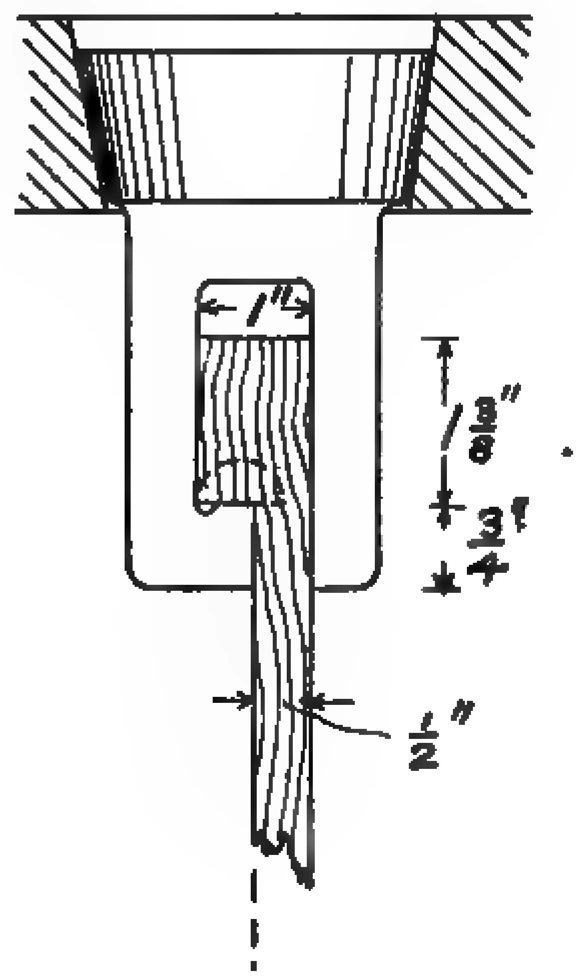



FIG. 92.

Shearing tests are usually made upon specimens shaped similarly to the one illustrated in Fig. 91, and the load is applied in an ordinary tensile testing machine to the plate marked P. Fig. 92 illustrates a shearing shackle used by Unwin for timber tests. The dimensions of the specimen must be carefully chosen so that the block fails by shear, and not by compression, the proportions of shearing to compression area being not more than 5, and preferably at only 3 or 4.

The direction of the grain should be noted—that is to say, whether *radial* or *tangential*—in relation to the shearing plane. It is usual to cut specimens for shear tests from beams which have been tested, and to determine their density and dryness after the shear test from the sheared-off pieces.

Tables CIII and CIV* give the results of the more reliable shearing tests.

There is not much difference between the shear strength along the grain for air-seasoned and green timber, the former being usually from 5 to 20 per cent. higher in value.

## Impact Tests upon Timber.

Timbers are often used under impact conditions, and it therefore becomes necessary to know, or to be able to calculate, its strength under such circumstances. Examples of parts under impact stresses are to be found in the felloes or spokes of automobile and cart wheels, the wooden framework of automobiles, the struts and tail skids of aeroplanes, and to a lesser extent the wing spars, longerons, and struts of aeroplanes.

The amount of data available upon the results of repeated loading and impact tests is limited, and there is here a field for research work.

The stress conditions under impact and repeated loading for metals have been considered in Vol. I, and the conclusions and results given there may help to appreciate the principles involved. Timber, however, differs from metals in its internal structure, so that the results of tests upon the one are not necessarily applicable to the other, without a fuller knowledge of the conditions.

Machines have been devised for testing specimen beams in bending impact; the beams are usually supported at the ends, and a heavy weight is caused to drop repeatedly upon the centre of the beam, the deflections being measured after each blow or recorded graphically. In the Olsen machine, shown in Fig. 93, the height of fall of the weight is increased

* See also Table LXXXIV on p. 263 and Table CVIII on p. 320.

## TABLE CIII.

### SHEARING STRENGTHS ALONG THE GRAIN OF TIMBERS.

| *Material.* | *Shearing Strength along Grain (Pounds per Square Inch).* | *Material.* | *Shearing Strength along Grain (Pounds per Square Inch).* |
|---|---|---|---|
| Ash* .. .. | 458–700 | Yellow pine* .. | 286–415 |
| Yellow birch* .. | 563–815 | Yellow pine† .. | 117–248 |
| White maple* .. | 367–647 | Spruce* .. .. | 253–374 |
| Red oak* .. .. | 726–999 | Spruce† .. .. | 153–397 |
| White oak* .. | 752–966 | Whitewood* .. | 382–406 |

## TABLE CIV.

### SHEARING STRENGTH ALONG AND ACROSS THE GRAIN OF AMERICAN TIMBERS.

(U.S. Forestry Service Circular 213 and Trautwine.)

| *Material.* | *Shearing Strength along the Grain for Green Wood.* | | *Shearing Strength across the Grain (Seasoned Wood).* |
|---|---|---|---|
| | *Surface of Shear Radial.* | *Surface of Shear Tangential.* | |
| Ash, white .. .. | 1360 | 1312 | 6280 |
| Beech .. .. | 1154 | 1375 | 5223 |
| Basswood .. .. | 560 | 617 | — |
| Oak .. .. .. | 1000–1200 | 1200–1400 | 4400–8500 |
| Cedar, white .. | — | — | 1519 |
| Hickory .. .. | 1000–1300 | 1100–1500 | 1370–1520 |
| Maple .. .. | 1160 | 1395 | 6355 |
| Pine, white .. .. | 649 | 639 | 2480 |
| Pine, yellow, N. .. | 686 | 706 | 4340 |
| Poplar .. .. | — | — | 4418 |
| Spruce .. .. | 607 | 624 | 3255 |
| Walnut, common .. | — | — | 4728 |
| Walnut, black .. | — | — | 2830 |
| Fir, Douglas .. | 853 | 858 | — |
| Chestnut .. .. | — | — | 1536 |

* Watertown Arsenal results upon small season specimens.

† Lanza's results estimated from tests upon beams failing by shearing along neutral plane.

FIG. 93.—THE OLSEN IMPACT TESTING MACHINE.

after each blow, and the deflections are continuously recorded right up to fracture.

The total work done upon the beam is a measure of its bending impact resistance or strength. The value of the work done is generally computed from the deflection record, knowing the weight and height of fall. It is often arranged to measure the height of rebound after each fall, together with the deflection. The energy absorbed by the beam is given by the following relation:

Energy absorbed = Weight [Initial Height − Final Height].

The heights are in each case measured from the same datum level—that is, from the original plane of the top surface of the beam.

A typical bending impact test record taken at the first, fifth, tenth, and final or thirteenth blows, is represented in Fig. 94 for progressively increasing heights of fall of the hammer. Vertical distances such as $H$, measured above the datum line (taken as the initial line of the top of the beam), represent drops and rebounds of the hammer, and distances below the line such as $D$, deflections or springings of the beams. The alternating character of this line series denotes the subsequent rebounds and deflections after each blow. In the first series there are about twelve marked rebounds before the hammer comes to rest, and in the tenth series about *eight*, whilst in the last there is, of course, no definite rebound, owing to fracture. Permanent set is denoted by the distance $S$ below the datum line of the termination point of each rebound series.

The elastic limit may be found from such records by plotting the square of the deflection (or $D^2$) against the height of drop ($h$); up to the elastic limit these quantities are proportional, but beyond same $D^2$ increases at a greater rate than $H$. The impact fibre stress $f_e$ at the elastic limit is given by—

$$f_e = \frac{3WH \cdot l}{D_e bd^2} \text{ pounds per square inch,}$$

where W = weight in pounds, $H$ = height of drop in inches,

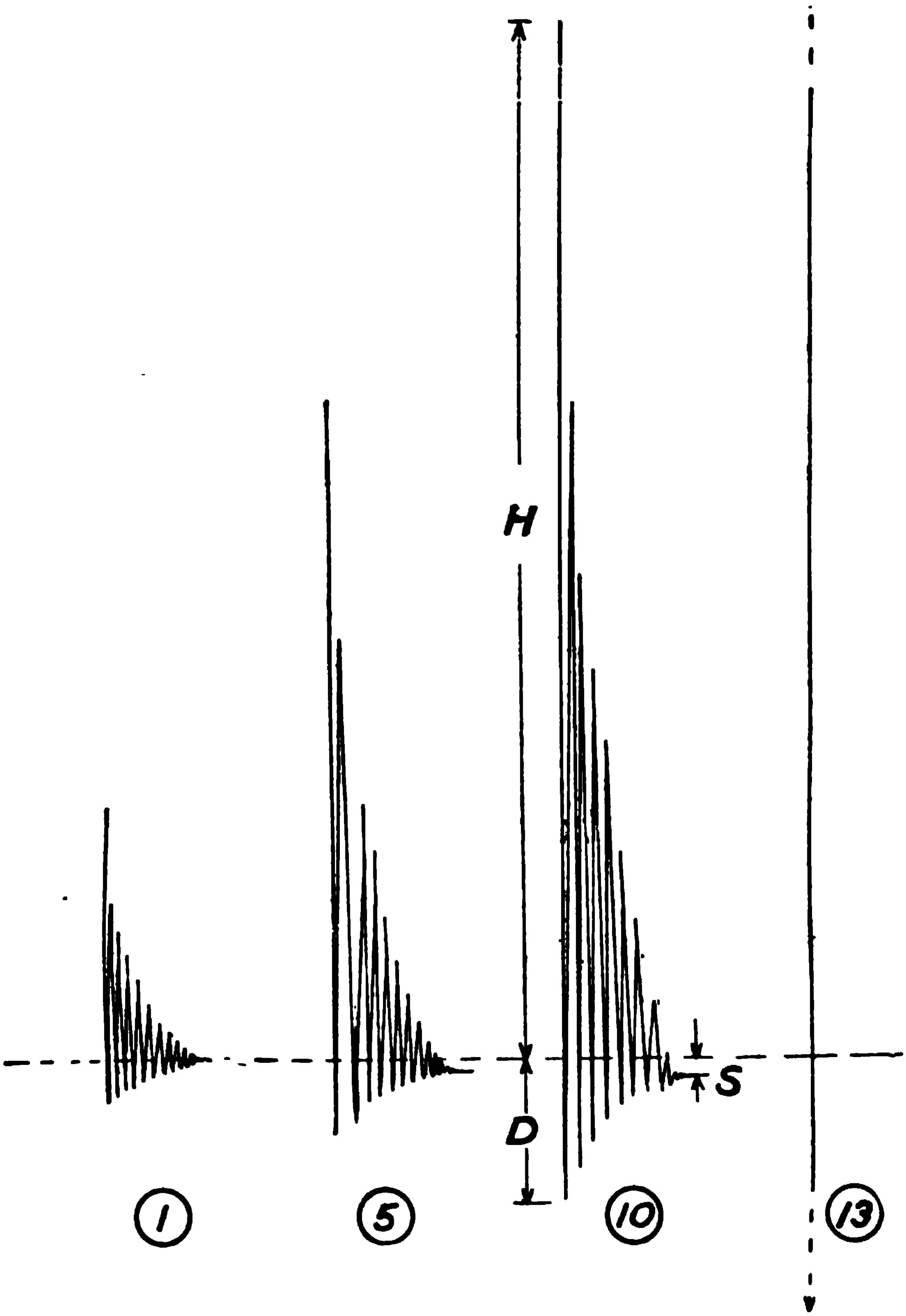



Fig. 94.—Record from Test on Olsen Machine.

$D_e$=deflection, in inches, at elastic limit, $b$=breadth, $d$=depth, and $l$=span of beam in inches, respectively.

The resilience of the beam under impact is given by—

$$W_E = \frac{WH}{lbd} \text{ inch-pounds per cubic inch.}$$

The sizes of beams most commonly employed for bending impact tests are 2 feet 6 inches span × 2 inches × 2 inches, 6 feet × 9 inches wide, and 8 feet × 12 inches wide.

The hammer weights vary from 50 to 500 pounds, and the final heights of fall from 10 inches to 7 feet, according to the size and material of the specimen.

It is possible in most types of impact machine to test the material under end-compression impact, but the bending test is more commonly employed; in many cases it is possible to test full-sized members under similar conditions of impact to those actually occurring in practice.

Another method which is employed for the impact testing of timber in this country consists in breaking at a single blow a suitably notched wooden specimen in an impact machine of the Izod type.*

The weight of the hammer in one very suitable machine of this type is 20 pounds, and the radius of the pendulum arm 24 inches; the specimen is struck at a height of 2½ inches above the notch.

The amount of energy required to fracture the specimen is computed from the initial and final angles (with the vertical of the pendulum arm)—that is, before and after the fracture.

If $W$ be the weight of the hammer, and $R$ the distance of its C.G. from the axis, and if $O_1$ and $O_2$ be the initial and final angles of swing, we have:

Initial energy (potential) before the blow $= WR(1 - \cos O_1)$
Final energy (potential) after the blow $= WR(1 - \cos O_2)$
Energy to fracture specimen $= WR(\cos O_2 - \cos O_1)$

Fig. 95 shows the dimensions of standard impact test specimens for ash or spruce, and it will be noted that these pieces

* See Vol. I for description of this machine.

must be cut so that their sides are radial and tangential to the annual rings, the direction of the blow being in the tangential direction shown. The standard impact test specification states that in the case of ash the energy absorbed in fracturing the specimen must exceed 10 foot-pounds, whilst for silver spruce it must not be less than 8 foot-pounds.

TABLE CV.

RESULTS OF BENDING IMPACT TESTS UPON SMALL CLEAR BEAMS OF GREEN TIMBER.

(U.S. Forestry Service.)

| *Material.* | *Fibre Stress at Elastic Limit, Pounds per Square Inch.* | *Modulus of Elasticity, Pounds per Square Inch.* | *Work done in Bending to Elastic Limit, Inch-Pounds per Cubic Inch.* |
|---|---|---|---|
| Ash, white .. .. | 11,710 | 1,564,000 | 4·93 |
| Basswood .. .. | 5480 | 917,000 | 1·84 |
| Beech .. .. | 11,760 | 1,501,000 | 5·10 |
| Birch, yellow .. | 11,080 | 1,812,000 | 3·79 |
| Elm, rock .. .. | 11,700 | 1,569,000 | 4·86 |
| Elm, white .. .. | 9910 | 1,138,000 | 4·82 |
| Maple, sugar .. | 11,680 | 1,680,000 | 4·55 |
| Oak, post .. .. | 11,260 | 1,596,000 | 4·41 |
| Oak, red .. .. | 10,580 | 1,506,000 | 4·16 |
| Oak, white .. .. | 9860 | 1,414,000 | 3·84 |
| Sycamore .. .. | 8180 | 1,165,000 | 3·22 |
| Cypress, bald .. | 8290 | 1,431,000 | 2·72 |
| Fir, Douglas.. .. | 8870 | 1,579,000 | 2·79 |
| Hemlock .. .. | 6330 | 1,025,000 | 2·19 |
| Pine, longleaf .. | 9680 | 1,739,000 | 3·02 |
| Pine, red .. .. | 7480 | 1,438,000 | 2·18 |
| Pine, Western yellow | 7070 | 1,115,000 | 2·51 |
| Pine, white .. .. | 6490 | 1,156,000 | 2·06 |
| Spruce, Englemann | 6300 | 1,076,000 | 2·09 |
| Tamarack .. .. | 7750 | 1,263,000 | 2·67 |

**Strength of Timber in Torsion.**

The manner of failure of timber in torsion is generally quite different from that of homogeneous metals, which fail by shearing across a section normal to the axis of torque. Most timbers are composed of bunches of longitudinal fibres, and upon the application of a torque about an axis along the grain the fibres become subjected to a tensile as well as to a

shearing stress, for each fibre tends to assume a helical shape, and in so doing experiences tension. The fibres also tend to contract laterally, due to this effect, and to pull apart or separate by mutual sliding past each other.

Yielding first occurs at the outermost fibres, which lose their adhesion and slide relatively to the next layer of fibres, thus weakening their power of resistance, and ultimately causing fracture by tension. The next layer receives an

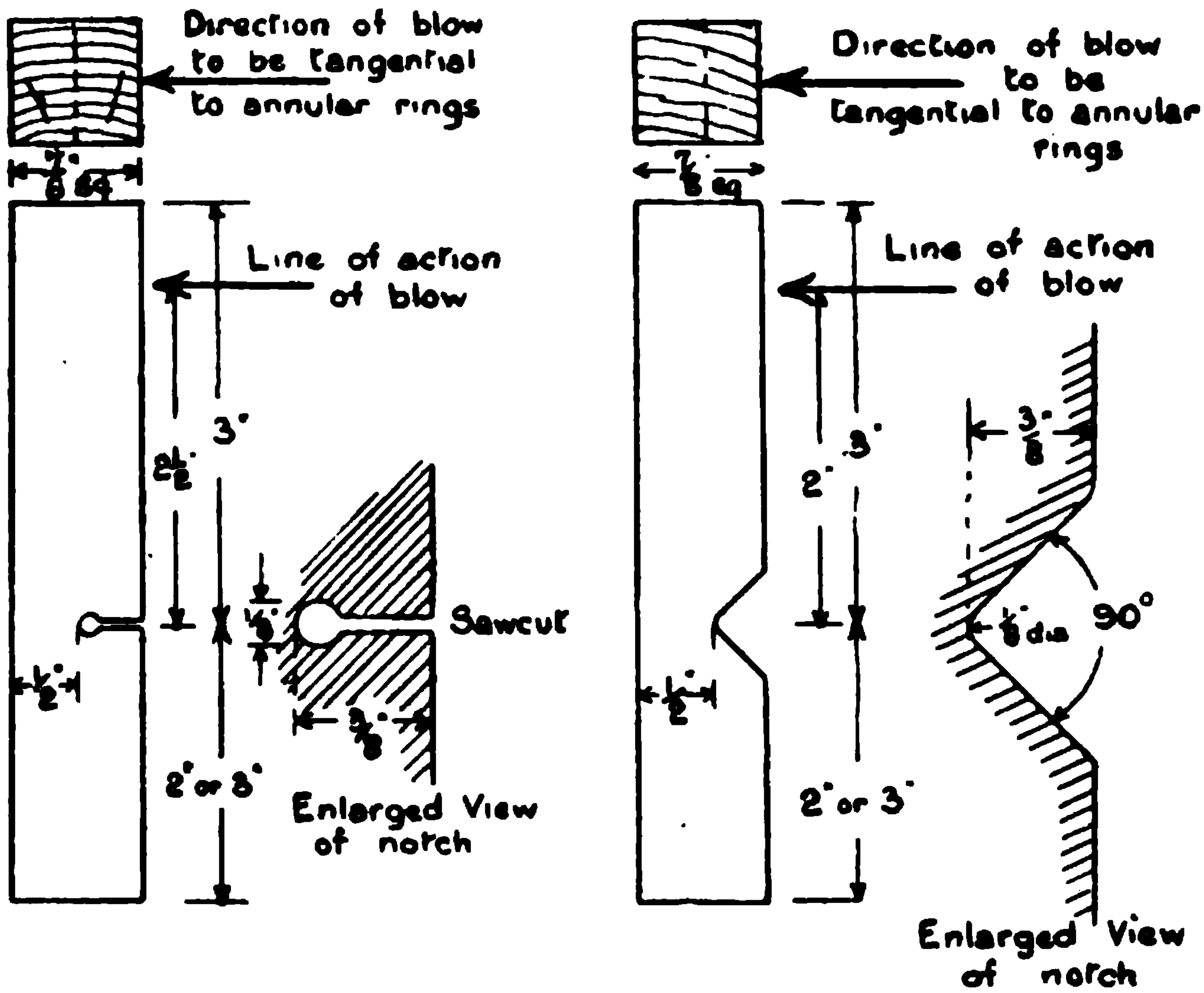



FIG. 95.—STANDARD IMPACT TEST SPECIMENS (IN WOOD).

increased stress as a result of the yielding of the outermost layer, and the intensity of stress tends to become more uniform towards the centre, until finally the whole of the fibres yield by relative shearing or sliding past, and by direct tension.

Tough and fibrous hardwoods twist quite a lot before fracturing, but brittle and certain softwoods break off in torsion with little angular twist, and often with a jagged fracture oblique to the axis.

The dimensions of test pieces for the Riehlé torsion-testing machine are $1\frac{1}{2}$ inches diameter $\times$ 18 inches long, with squared ends 4 inches long, and the rate of torsional loading is 22°

per minute. It is usual in torsional tests to make simultaneous observations of loads and angular deflection; in some cases these are automatically recorded. The equivalent shear stress at the elastic limit and the modulus of rigidity can then be estimated from the relations—

$$(1)\ f_e = \frac{5{\cdot}1\ T}{d^3},\ \text{and}\ (2)\ C = \frac{114{\cdot}6\, f_e \cdot l}{\theta \cdot d},$$

where $f_e$=shear stress at elastic limit in pounds per square inch, C=modulus of rigidity in pounds per square inch, T=torque at elastic limit in pounds inches, $l$=gauge length in inches, $d$=diameter in inches, $\theta$=angle of torsion, in degrees, at elastic limit.

The amount of information available in connexion with the torsional properties of different timbers is very limited, probably on account of the secondary importance of the torsional strength value.

The results of tests made by Bevan are given in Table CVI. These results indicate that in general the heavier

TABLE CVI.

TORSIONAL STRENGTHS OF TIMBERS. (Bevan.)

| *Material.* | *Mean Density, Pounds per Cubic Foot.* | *Torsion, Pounds per Square Inch.* | *Material.* | *Mean Density, Pounds per Cubic Foot.* | *Torsion, Pounds per Square Inch.* |
|---|---|---|---|---|---|
| Brazil .. .. | 65½ | 37,800 | Birch .. .. | 39½ | 17,250 |
| Boxwood .. | 63½ | 30,000 | Chestnut, sweet | 39¼ | 18,360 |
| African teak .. | 63¼ | 27,300 | Walnut .. | 39 | 19,784 |
| Lancewood .. | 57½ | 25,245 | Sycamore .. | 39 | 22,900 |
| Hornbeam .. | 50¾ | 26,411 | Pine From .. | 32 | 10,500 |
| Elder .. .. | 49¼ | 22,285 | Pine To .. | 38 | 14,750 |
| Beech .. .. | 48½ | 21,243 | Scots fir .. | 35¼ | 13,700 |
| Ash .. .. | 46½ | 20,300 | Larch .. .. | 35 | 18,970 |
| Oak From .. | 42 | 12,000 | Deal .. .. | 35 | 11,200 |
| Oak To .. | 49 | 20,000 | Spruce .. | 28½ | — |
| Acacia, Robinia | 44 | 28,293 | Poplar .. | 26 | 9473 |
| Elm .. .. | 43½ | 13,500 | Bamboo .. | 28 | 21,500 |
| Mountain ash .. | 42 | 13,933 | Cedar, incense | 30 | 12,500 |
| Hazel .. .. | 40 | 26,325 | | | |

woods are stronger in torsion than the lighter woods, but that the torsional and transverse strengths do not appear to be related, and that flexibility is not an indication of a torsional strength.

It should be pointed out that the values given in Table CVI. are open to a certain amount of question, and so should only be taken as an approximate quantitative indication of the torsional strengths.

## Hardness of Timber.

The usual meaning of the term hardness when applied to timber is its resistance to indentation, and the common method of testing for comparative hardness is by indenting the specimen with a steel ball of 0·444 inch diameter (giving an area of ¼ square inch) down to a depth of indentation equal to the radius (0·222 inch). The value of the load causing such indentation is taken as a measure of the hardness. It is usually found that the hardness is greater in the end direction (grain "end-on") than in the transverse direction, and that the hardwoods are much "harder" than the softwoods. The hardness value bears a relation to the density of the timber, approximately, as follows:

$$H = k \cdot \rho^{2.0-2.2},$$

where $H$=hardness number, $\rho$=the density, and $k$=a constant.

It is fairly certain that the hardness will also depend upon the history, mode and rate of growth of the tree, and upon the position of the timber in the tree itself.

In timber hardness tests the rate of indentation should be specified; in the U.S. Forestry Service tests the rate was 0·25 inch per minute, and the specimens measured 2 inches × 2 inches × 6 inches.

## TABLE CVII.

### Hardness of Timbers in Green Condition.*

(Loads required to imbed steel ball of 0·444 inch diameter to a depth equal to one-half its diameter.)

| *Material.* | *Tangential Surface.* | *Radial Surface.* | *End Surface.* | *Average.* |
|---|---|---|---|---|
| | *Pounds.* | *Pounds.* | *Pounds.* | *Pounds.* |
| Oak, white .. .. | 1147 | 1163 | 1183 | 1164 |
| Oak, post .. .. .. | 1081 | 1068 | 1139 | 1099 |
| Ash, white .. .. | 1017 | 1000 | 1121 | 1046 |
| Beech .. .. .. | 918 | 897 | 1012 | 942 |
| Maple, sugar .. .. | 901 | 918 | 992 | 937 |
| Elm, rock .. .. .. | 893 | 883 | 954 | 910 |
| Hackberry .. .. | 773 | 795 | 829 | 799 |
| Elm, slippery .. .. | 687 | 757 | 919 | 788 |
| Birch, yellow .. .. | 739 | 768 | 827 | 778 |
| Sycamore .. .. .. | 599 | 560 | 664 | 608 |
| Basswood .. .. .. | 217 | 226 | 273 | 239 |
| Pine, longleaf .. .. | 521 | 502 | 574 | 532 |
| Fir, Douglas .. .. | 416 | 399 | 415 | 410 |
| Hemlock .. .. .. | 334 | 354 | 463 | 384 |
| Tamarack .. .. | 370 | 380 | 401 | 384 |
| Pine, red .. .. .. | 340 | 345 | 355 | 347 |
| Fir, white .. .. .. | 334 | 322 | 381 | 346 |
| Pine, Western yellow .. | 342 | 307 | 334 | 324 |
| Pine, white .. .. | 299 | 294 | 304 | 299 |
| Spruce, Engelmann .. | 274 | 253 | 272 | 266 |
| Fir, Alpine .. .. | 235 | 203 | 284 | 241 |

### Resistance to Wear or Abrasion.

In some respects the hardness value is an indication of the wearing properties of a timber, but there are other factors, such as the strength in different directions, arrangement and cohesion of the fibres, which also influence the wearing properties.

It is well known that edge grain wears much better than flat grain, and that hardwoods wear better than softwoods. Knotty timber wears unevenly, the knots ultimately standing right up above the other parts and forming a very irregular surface.

* U.S. Forestry Service Circular 213.

It is important to know the wearing properties of floor-boards, plywoods used for flooring, wooden rollers, bearings, and paving blocks.

The wearing properties of timbers are usually tested by comparison with those of a standard block of chosen timber, by means of an abrasion or flat sand-papering machine. In the Dorry abrasion machine* the wear of the specimen block is compared with that of a sugar-maple block of 10 per cent. moisture, each block being held upon the same mean radius of a horizontal sand-paper disc, each with a 26 pound weight. The specimens measure 2 inches × 2 inches, and the speed of rotation is 65 R.P.M. The relative losses in weights of the blocks after a given period of running are taken as a relative measure of their wearing qualities.

Another method† consists in subjecting the specimen to the abrading action of a sand blast, utilizing superheated steam to eject the quartz particles through a nozzle on to the specimen. In this case, also, the loss in weight after an interval of a minute or two is compared with that of a standard wood under the same conditions.

## Miscellaneous Properties.

**Cleavability** is usually defined as the property of splitting under the influence of a wedging action. This property is of importance in connexion with the nailing or screwing of timbers, and commercial splitting up for various purposes. It is found that a low degree of cleavability is suitable for the timber of parts requiring nailing or screwing.

Timber splits most readily radially end-on, then tangentially end-on, and least easily in the case of tough, fibrous, knotty, and wavy grained woods. Softwoods are invariably more cleavable than hardwoods, and dry timbers are more readily split than wet timbers.

* Employed by the U.S. Forestry Service.

† Used for abrasion tests of New South Wales timbers by Professor W. H. Warren.

Cleavability depends partly upon the tensile strength across the grain, and partly upon the bending or transverse strength.

The standard U.S. Forestry Service test is made upon specimens measuring 2 inches × 2 inches × 3¾ inches in a static testing machine with a given rate of loading. The specimen is grooved to a 1 inch diameter at one end, and the testing machine hooks are fitted into this groove in such a manner that when the load is applied they move outwards and the block splits. The results are expressed in terms of the maximum load causing cleavage per square inch of width.

**Toughness.**—This term is somewhat loosely applied to the combined properties of transverse bending strength, flexibility, and resistance to impact. A tough wood will be difficult to bend, split, or fatigue under repeated loadings, and toughness may be regarded as opposed to brittleness. The toughest woods are ash, hickory, oak, and elm, whilst softwoods, and woods such as poplar, basswood, and white cedar, are the least tough.

**Resilience.**—This property is defined as the springiness or capacity for storing up work by elastic deformation, and giving this work out when the load is released.

The product of the fibre stress at the elastic limit and the strain per unit volume is taken as a measure of the resilience, no matter what the nature of the stress is. In the case of the transverse bending of a beam supported at its ends and loaded in the middle, the resilience is equal to the elastic load value multiplied by the central deflection. The subject of resilience under bending action is closely connected with that of transverse bending, and to the bending impact already considered.

It has been shown that the amount of energy which can be stored up, in the ordinary static bending method, up to the elastic limit, varies from about 0·5 to 0·8 inch-pound per cubic

inch in the case of softwoods, such as firs, pines, and spruces, to from 0·8 to 1·5 in the case of hardwoods, such as ash, hickory, oak, and elm.

In bending impact the resilience value varies from about 2 to 3 for the softwoods, and from 3 to 5 for the hardwoods.

**Nail or Spike Holding Property.**—This property is of importance in all cases of timber parts held to other parts by means of nails, screws, or spikes, and depends upon the resilience or elasticity of the timber, and upon its cohesion and frictional properties.

When a nail is driven into a piece of wood transversely, the fibres are cut, bent, and compressed, and the severed portions tend to react against the surfaces of the nail by direct pressure and by friction.

The resistance offered to withdrawal of the nail will vary with the roughnesses of the surface of the nail and the nature of the timber. Hardwoods are harder to penetrate than softwoods, and end grain is easier to penetrate and withdraw from than transverse grain.

The resistance to withdrawal offered by nails and by wood screws of the same diameter and in the same material is approximately as 1 to 2.

The direct force required to withdraw a $\frac{1}{8}$-inch spike varies from 2000 to 3000 pounds for untreated timbers to from 2500 to 3500 pounds for treated timbers, and the force varies as the depth of penetration.

## Shearing Strength of Wood Screws.

There is not much available data on the subject of the strength of wood screws in various woods, under tension, shear and bending action, and a useful field of research is here suggested.

In the case of the shear strength of wood screws of different sizes in mahogany and walnut, some data are available from the results of tests made by the Air Department of the Admiralty

during the late war. The following results were obtained for the shearing strengths—

| *Size of Screw.* | *Number of Screws.* | *Breaking Pull in Pounds.* | *Type of Wood.* | *Failing Load per Single Screw. Pounds.* |
|---|---|---|---|---|
| [illegible] inch No. 2 | 5 | 615 | Mahogany | 123 |
| [illegible] ,, No. 2 | 5 | 620 | Mahogany | 124 |
| [illegible] ,, No. 1 | 6 | 595 | Mahogany | 99 |
| [illegible] ,, No. 1 | 6 | 630 | Walnut | 105 |
| [illegible] ,, No. 0 | 6 | 605 | Mahogany | 101 |
| [illegible] ,, No. 0 | 6 | 545 | Walnut | 91 |
| [illegible] ,, No 2 | 6 | 535 | Mahogany | 89 |
| [illegible] ,, No. 2 | 6 | 495 | Walnut | 82 |
| $\frac{1}{4}$ ,, No. 00 | 8 | 565 | Mahogany | 71 |
| $\frac{1}{4}$ ,, No 00 | 8 | 545 | Walnut | 68 |

**Conductivity.**—Wood is a poor conductor of heat and electricity, but is a good sound conductor, more especially along its length.

Wet or green wood is a conductor of electricity, and the results of tests upon preserved timbers* showed that—

(*a*) The resistance varies directly as the length and inversely as the cross-section.

(*b*) The resistance is least along the grain, and greatest tangentially to the annual rings.

(*c*) The resistance varies inversely as the moisture content.

(*d*) The resistance of non-porous woods, such as pines, is higher than that of porous woods, such as oaks.

(*e*) The treatment by the creosote process does not appreciably affect the resistance, but by the zinc chloride process the resistance varies inversely as the amount of salt present.

The velocity of sound in wood is about 11,000 feet per second in the case of pine, and 16,700 in the case of aspen.

The coefficient of linear expansion of wood is about $\frac{1}{6}$ to $\frac{1}{8}$ of

* "The Electrical Resistance of Timber," Butterfield. *Amer. Eng. News*, April, 1911.

that of iron; it is also considerably less in the longitudinal direction than for the radial.

Thus, in the case of oak the radial linear expansion coefficient was found to be 0·0000544, whilst in the longitudinal direction it was 0·00000492, or only about one-eleventh, of the radial value.

The calorific or heating value of timber is only about $\frac{1}{2}$ to $\frac{1}{3}$ that of average coal. The calorific value of English oak, when dry, is about 7500 B.T.U.'s per pound; the average value for timbers may be taken at 6600 B.T.U.'s.

## TABLE CVIII.

### Showing the Physical Properties of Various Timbers.

| *Common and Botanical Names.* | *Specific Gravity based on Volume and Weight when Oven-Dry.* | | | *Shrinkage from Green to Oven-Dry Condition.* | | *Static Bending.* | | | | *Compression Parallel to Grain.* | *Compression Perpendicular to Grain.* | | *Hardness Side.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Average.* | *Minimum permitted.* | *Weight at 15 per Cent. Moisture.* | *Radial.* | *Tangential.* | *Fibre Stress at Elastic Limit.* | *Modulus of Rupture.* | *Modulus of Elasticity.* | *Work to Maximum Load.* | *Maximum Crushing Strength.* | *Fibre Stress at Elastic Limit.* | *Shearing Strength Parallel to Grain.* | *Load Required to imbed 0·444 Inch Ball to ½ its Diameter.* |
| Hardwoods. | | | Lbs. per Cu. Ft | Per Cent. | Per Cent. | Lbs. per Sq. In. | Lbs. per Sq. In. | 1000 Lbs per Cu. In. | In.-Lbs. per Sq. In. | Lbs. per Sq. In. | Lbs. per Sq In. | Lbs. per Sq In. | Pounds. |
| Ash, commercial white (*Fraxinus americana, F. lanceolata, F. quadrangulata*) | 0·62 | 0·56 | 40 | 4·5 | 7·1 | 7700 | 12,700 | 1500 | 14·2 | 6000 | 1300 | 1750 | 1500 |
| Ash, black (*F. nigra*) . . | 0·53 | 0·48 | 35 | 5·0 | 7·8 | 5800 | 10,500 | 1400 | 14·1 | 4900 | 800 | 1350 | 740 |
| Basswood (*Tilia americana*) | 0·40 | 0·36 | 25 | 6·6 | 9·3 | 4700 | 7200 | 1300 | 6·4 | 3800 | 400 | 880 | 340 |
| Beech (*Fagus atropunicea*) | 0·66 | 0·60 | 41 | 4·8 | 10·6 | 7400 | 12,600 | 1500 | 13·3 | 5900 | 1100 | 1700 | 1060 |
| | 0·67 | 0·61 | 43 | 7·0 | 8·5 | 8400 | 13,500 | 1800 | 17·6 | 6600 | 1000 | 1620 | 1070 |
| Cherry, black (*Prunus serotina*) | 0·53 | 0·48 | 35 | 3·7 | 7·1 | 7300 | 10,600 | 1400 | 12·0 | 5800 | 700 | 1500 | 880 |
| Cottonwood (*Populus deltoides*) | 0·43 | 0·39 | 28 | 3·9 | 9·2 | 4500 | 7000 | 1200 | 7·3 | 3800 | 400 | 900 | 380 |
| Elm, rock (*Ulmus racemosa*) | 0·66 | 0·60 | 44 | 4·8 | 8·1 | 6700 | 12,500 | 1400 | 19·3 | 5800 | 1200 | 1650 | 1200 |
| Gum, red (*Liquidambar styraciflua*) | 0·53 | 0·48 | 34 | 5·2 | 9·9 | 6700 | 10,400 | 1400 | 11·0 | 4900 | 700 | 1500 | 650 |
| Hickory (true hickories) (*Hicoria glabra, laciniosa, alba, ovata*) | 0·81 | 0·73 | 50 | 7·3 | 11·4 | 8900 | 16,300 | 1900 | 28·0 | 7300 | 1800 | 1800 | — |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mahogany, true (*Swietenia mahagoni*) | 0·54 | 0·50 | 36 | 3·5 | 4·2 | 7000 | 10,000 | 1300 | 9·1 | 5500 | 1000 | 1420 | 800 |
| Mahogany, African (*Khaya* | 0·50 | 0·46 | 34 | 4·8 | 5·5 | 7100 | 10,400 | 1400 | 10·3 | 5100 | 900 | 1270 | 730 |
| | 0·66 | 0·60 | 42 | 4·8 | 9·2 | 8100 | 12,900 | 1600 | 12·9 | 6500 | 1200 | 1990 | 1200 |
| | 0·72 | 0·65 | 46 | 5·3 | 9·2 | 6700 | 12,000 | 1400 | 12·7 | 5900 | 1300 | 1760 | 1270 |
| Poplar, yellow (*Liriodendron tulipifera*) | 0·42 | 0·38 | 28 | 4·1 | 6·9 | 4800 | 7500 | 1300 | 6·2 | 4100 | 400 | 900 | 370 |
| Walnut, black (*Juglans nigra*) | 0·56 | 0·52 | 38 | 5·2 | 7·1 | 7900 | 11,900 | 1500 | 13·1 | 6100 | 1000 | 1300 | 950 |
| CONIFERS. | | | | | | | | | | | | | |
| Cedar, incense (*Libocedrus decurrens*) | 0·36 | 0·32 | 26 | 3·3 | 3·7 | 4900 | 7100 | 1000 | 6·0 | 4300 | 600 | 850 | 430 |
| Cedar, Port Orford (*Chamæcyparis lawsoniana*) | 0·47 | 0·42 | 31 | 5·2 | 8·1 | 6200 | 10,300 | 1700 | 9·7 | 5300 | 700 | 1160 | 580 |
| Cedar, Western red (*Thuja plicata*) | 0·34 | 0·31 | 23 | 2·5 | 5·1 | 4200 | 6400 | 1000 | 5·5 | 4000 | 400 | 790 | 300 |
| Cedar, white (Northern) (*T. occidentalis*) | 0·32 | 0·29 | 22 | 2·1 | 4·9 | 4200 | 5800 | 750 | 5·1 | 3400 | 350 | 800 | 300 |
| Douglas fir (*Pseudotsuga taxifolia*) | 0·52 | 0·47 | 34 | 5·0 | 7·9 | 6800 | 9700 | 1780 | 7·2 | 6000 | 750 | 1020 | 580 |
| Pine, sugar (*Pinus lambertiana*) | 0·39 | 0·36 | 27 | 2·9 | 5·6 | 5300 | 7400 | 1100 | 5·0 | 4300 | 540 | 950 | 410 |
| Pine, Western white (*P. monticola*) | 0·45 | 0·40 | 29 | 4·1 | 7·4 | 5100 | 7800 | 1400 | 6·9 | 4800 | 480 | 670 | 360 |
| Pine, white (*P. strobus*) .. | 0·39 | 0·36 | 27 | 2·2 | 5·9 | 5100 | 7400 | 1200 | 6·1 | 4500 | 530 | 850 | 390 |
| Pine, Norway (*P. resinosa*) | 0·51 | 0·46 | 33 | 4·6 | 7·2 | 7900 | 10,900 | 1700 | 6·1 | 6100 | 720 | 1150 | 540 |
| Spruce, red, white, Sitka (*Picea rubens, canadensis, sitchensis*) | 0·41 | 0·36 | 27 | 3·9 | 7·5 | 5100 | 7900 | 1300 | 7·4 | 4300 | 500 | 920 | 430 |
| Cypress, bald (*Taxodium distichum*) | 0·47 | 0·42 | 31 | 3·8 | 6·0 | 6100 | 8900 | 1300 | 6·8 | 5400 | 670 | 940 | 460 |

## TABLE CIX.

### STRENGTH OF AMERICAN TIMBERS.

(American Association of Railway Superintendents of Bridges and Buildings, October, 1895.)

| *Kind of Timber.* | *Tension.* | | *Compression.* | | | *Transverse Rupture.* | | *Shearing.* | |
|---|---|---|---|---|---|---|---|---|---|
| | | | *With Grain.* | | | | | | |
| | *With Grain.* | *Across Grain.* | *End Bearing.* | *Columns under 15 Diameters.* | *Across Grain.* | *Extreme Fibre Stress.* | *Modulus of Elasticity.* | *With Grain.* | *Across Grain.* |
| *Average Ultimate Breaking Stresses in Pounds per Square Inch:* | | | | | | | | | |
| White oak .. .. .. .. | 10,000 | 2000 | 7000 | 4500 | 2000 | 6000 | 1,100,000 | 800 | 4000 |
| White pine .. .. .. .. | 7000 | 500 | 5500 | 3500 | 800 | 4000 | 1,000,000 | 400 | 2000 |
| Southern longleaf or Georgia yellow pine | 12,000 | 600 | 8000 | 5000 | 1400 | 7000 | 1,700,000 | 600 | 5000 |
| Douglas, Oregon, and Washington fir or pine { Yellow fir | 12,000 | — | 8000 | 6000 | 1200 | 6500 | 1,400,000 | 600 | — |
| Douglas, Oregon, and Washington fir or pine { Red fir .. | 10,000 | — | — | — | — | 5000 | — | — | — |
| Northern or shortleaf yellow pine | 9000 | 500 | 6000 | 4000 | 1000 | 6000 | 1,200,000 | 400 | 4000 |
| Red pine .. .. .. .. | 9000 | 500 | 6000 | 4000 | 800 | 5000 | 1,200,000 | — | — |
| Norway pine .. .. .. | 8000 | — | 6000 | 4000 | 800 | 4000 | 1,200,000 | — | — |
| Canadian (Ottawa) white pine .. | 10,000 | — | — | 5000 | — | — | — | 350 | — |
| Canadian (Ontario) red pine .. | 10,000 | — | — | 5000 | — | 5000 | 1,400,000 | 400 | — |
| Spruce and Eastern fir .. .. | 8000 | 500 | 6000 | 4000 | 700 | 4000 | 1,200,000 | 400 | 3000 |
| Hemlock .. .. .. .. | 6000 | — | — | 4000 | 600 | 3500 | 900,000 | 350 | 2500 |
| Cypress .. .. .. .. | 6000 | — | 6000 | 4000 | 700 | 5000 | 900,000 | — | — |
| Cedar .. .. .. .. | 8000 | — | 6000 | 4000 | 700 | 5000 | 700,000 | — | 1500 |
| Chestnut .. .. .. .. | 9000 | — | — | 5000 | 900 | 5000 | 1,000,000 | 600 | 1500 |
| California redwood .. .. .. | 7000 | — | — | 4000 | 800 | 4500 | 700,000 | 400 | — |
| California spruce .. .. .. | — | — | — | 4000 | — | 5000 | 1,200,000 | — | — |
| Factors of safety recommended | 10 | 10 | 5 | 5 | 4 | 6 | 2 | 4 | 4 |

## TABLE CX

STRENGTH OF AUSTRALIAN TIMBERS. (Professor Warren.)

| *Timber.* | *Weight per Cubic Foot. Pounds.* | *Mean Values, in Pounds per Square Inch.* | | | |
|---|---|---|---|---|---|
| | | *Modulus of Rupture on Beams* 54×6×4 *Inches.* | *Tensile Strength.* | *Compressive Strength on Pieces* 12×3×3 *Inches.* | *Shearing Strength on Pieces* 6×6×2 *Inches.* |
| *N.S.W. Timbers:* | | | | | |
| Ironbark .. | 75·18 | 18,204 | 17,900 | 10,500 | 2200 |
| Tallow wood .. | 77·06 | 15,300 | 13,400 | 8500 | 1660 |
| Blackbutt .. | 66·69 | 14,800 | 21,000 | 8600 | 1700 |
| Blue gum .. | 73·64 | 14,700 | 15,900 | 7800 | 1800 |
| Grey gum .. | 67·32 | 17,600 | 22,000 | 9500 | 2100 |
| Spotted gum .. | 62·19 | 15,300 | 16,400 | 8500 | 2200 |
| Turpentine .. | 69·34 | 14,400 | 17,800 | 8500 | 1600 |
| Grey or white box | 73·62 | 15,950 | 21,564 | 8021 | 2110 |
| Murray red gum | 62·19 | 11,267 | 13,618 | 9397 | 2039 |
| Stringybark .. | 71·33 | 13,083 | 15,976 | 6098 | 2089 |
| *Western Australian Timbers:* | | | | | |
| Jarrah .. | 62·0 | 12,040 | 16,047 | 6839 | 1878 |
| Karri .. .. | — | 11,208 | 13,920 | 7132 | 1637 |
| Red gum .. | 62·5 | 10,739 | 22,725 | 5476 | 1556 |

# CHAPTER VII

# AIRCRAFT FABRICS AND COVERINGS

## AEROPLANE FABRICS AND COVERINGS

FOR covering the framework of aeroplane wings and control surfaces, a number of different materials have been suggested, and in many cases employed, which may be briefly classified as follows, namely—

(*a*) Vegetable and animal fibres: Calico, cotton, silk, goldbeaters' skin, paper linen, cambric, muslin, oiled silk, rubbered fabrics, etc.

(*b*) Celluloid sheets (for transparency) and red fibre.

(*c*) Thin plywoods, or fabric-covered veneers.

(*d*) Metal sheets, such as very thin high tensile steel, aluminium, and aluminium alloys.

The various materials classified under heading (*a*) have now, as the result of experience, been reduced to cotton and linen fabrics, treated with special varnishes or dopes to render them oil and water-tight.

### Transparent Coverings.

In a limited number of cases thin sheets of celluloid or a similar non-inflammable transparent covering have been used with the object of rendering machines invisible at a distance, for improving the view, and for facilitating the examination of the internal structure. The use of this material* is now limited to only a small portion of the machine, such as the centre section, parts of the floor, sides, or nose (in the case of pusher or multi-engined fuselages) of bodies, aileron inspection panels, etc. In general, it is the increased weight of the coverings of this type, combined with the tendency to

* Triplex glass is much used for the front cockpit panels of large machines.

warp, cockle, or wrinkle under temperature changes, which obviates its use for large surfaces.

For the same area, the thinnest cellulose-base material that would be employed, namely, one of thickness about a millimetre would weigh about 5 or 6 times as much as a doped linen fabric; this difference upon a large area such as that of the double wing surface of an aeroplane would be considerable.

The following table* gives the results of some tests upon transparent cellulose acetate sheets—

## TABLE CXI.

### Properties of Transparent Cellulose Acetate Sheets.

| *No.* | *Thickness in inches.* | *Weight in ounces per sq. yard.* | *Tensile strength (pounds per sq. inch)* | | *Maximum difference in tests (in per cent. of average value).* | |
|---|---|---|---|---|---|---|
| | | | *A* | *B* | *A* | *B* |
| 1 | ·010 | 9·33 | 55·3 | 57 | 10·8 | 10·5 |
| 2 | ·016 | 15·49 | 106·3 | 85·8 | 14·1 | 8·1 |
| 3 | ·024 | 22·96 | 127·1 | 130 | 30·6 | 25·2 |
| 4 | ·032 | 30·35 | 178·6 | 187·7 | 21·2 | 2·6 |
| 5 | ·064($\frac{1}{16}$) | 59·02 | 326 | 345·8 | 10·7 | 0·8 |

Columns *A* and *B* denote tests in directions along and across the length of the sheets.

Tests were made on a Riehle machine, 1 inch strips, 1 inch jaw, 3 inches between the jaws. The speed of test was 18 inches per minute.

It was stated that the above material was quite flexible, and that it could be bent double several times without cracking; it was found to tear very easily when once cut, and was non-inflammable.

* Report No. 6. Amer. Advisory Committee for Aeronautics, 1915.

**Plywoods, Etc.**

To a limited extent, thin plywoods have been used as coverings for portions of the wings and bodies of aeroplanes.* Plywood of maple, cotton-wood, and similar materials have been successfully employed for making the bodies of aeroplanes. These bodies are not only more permanent and stronger than the ordinary fabric-covered, wire-braced, wooden girder type of fuselage, but enable much better streamline shapes to be obtained, and are more attractive to the eye; moreover, for quantity production they offer advantages over the other type.

The plywood, which varies in thickness from about $\frac{1}{16}$ to $\frac{1}{8}$ inch, is now generally glued and tacked to skeleton cross-sections or formers of the correct shape, held apart by about six or eight longitudinal rails, somewhat similar to boat construction. In one or two instances the veneers are built up upon a mould, the alternate layers running in different directions, the inside and outside surfaces being covered with glued fabric. In some cases a veneer covered upon each side with a linen fabric, glued and pressed on, is employed for bodies, curved sections, and similar purposes. Another covering sometimes used for watertight aircraft coatings consists of two layers of thin cedar or mahogany veneer with a layer of strong linen fabric between, glued and sewn at intervals.

Metal coverings have been suggested from time to time, but, so far, have found little application, on account either of their excessive weight when the thickness is just sufficient to prevent accidental buckling, indentation, or similar injury, or of the excessive fragility of the sheets when thin enough to conform to the weight limitations.

Corrugated sheets of an aluminium alloy have been used upon certain military machines for wing coverings,† but it is

* See "Fuselage Design and Construction." A. W. Judge. (Messrs. Selwyn & Co., London.)

† Notably upon the German Junker machines used for low flying offensive work.

known that the weight of these machines was appreciably increased by same.

Table CXII shows the weights of various coverings applicable for aircraft and seaplanes, etc.

TABLE CXII.

WEIGHTS OF VARIOUS COVERING MATERIALS.

| *Material.* | *Weight per sq. yard.* |
|---|---|
| | *Pounds.* |
| Ordinary Irish Linen Aeroplane Fabric Undoped .. | 0·25 |
| ,, ,, ,, ,, ,, Doped .. .. | 0·40 |
| Heavy Seaplane Linen Fabric Doped .. .. | 0·70 |
| Parallel Rubbered Cotton Kite Balloon Fabric .. .. | 0·85 |
| Two-ply Cedar, 1·5 millimetre thick, with a layer of fine linen glued to each side .. .. .. .. .. | 1·90 |
| Proofed Silk. Aluminium painted (Airships) .. .. | 0·80 |
| Single-ply Cedar, 1 millimetre thick, with layer of fine fabric on each side .. .. .. .. .. | 1·60 |
| Single-ply Satin Walnut, 1 millimetre thick, with one layer of fine fabric glued on .. .. .. .. .. | 1·20 |
| Two-ply Maple, 1 millimetre thick .. .. .. | 1·25 |
| ,, ,, 1 ,, ,, .. .. .. | 2·50 |
| ,, ,, 3 ,, ,, .. .. .. | 3·75 |
| Three-ply Maple, ⅛ inch (3·2 millimetres) thick .. .. | 3·90 |
| Transparent Cellulose Acetate Sheet, 0·25 millimetres thick | 0·60 |
| ,, ,, ,, ,, 0·50 ,, ,, | 1·20 |
| ,, ,, ,, ,, 1·00 ,, ,, | 2·40 |
| ,, ,, ,, ,, 2·00 ,, ,, | 4·80 |
| Aluminium Sheet 24 S.W.G. (0·559 millimetres) .. .. | 2·74 |
| ,, ,, 28 ,, (0·376 millimetres) .. .. | 1·84 |
| ,, ,, 30 ,, (0·315 millimetres) .. .. | 1·54 |
| Steel Sheet 24 S.W.G. (0·559 millimetres) .. .. | 7·92 |
| ,, ,, 28 ,, (0·376 millimetres) .. .. | 5·33 |
| ,, ,, 30 ,, (0·315 millimetres) .. .. | 4·47 |

## The Testing of Aircraft Fabrics.

For aircraft purposes it is desirable that fabric coverings should possess the following characteristics, namely—

(*a*) The *Weight per Unit Area* shall not exceed a certain maximum value. For example, ordinary aeroplane wing coverings undoped should not exceed 4 ounces per square yard; seaplane coverings 6 or 7 ounces per square yard; kite-balloon coverings 8 to 12 ounces per square yard.

(*b*) The *Tensile Strength per Unit Width* should be the same in both warp* and weft*; for ordinary aeroplane and seaplane fabrics the minimum allowable tensile strengths are about 90 pounds and 100 pounds per inch width respectively. Balloon fabrics usually have a tensile strength of from 80 to 150 pounds per inch width, according to the purpose for which it is used.

It has been found that the tensile strength of fabric increases slightly when the rate of loading is increased above slow rates; this increase of strength ceases, however, after a certain limiting rate of loading is reached. For example in the case of *silk*, the same tensile strength is obtained for rates of loading varying from zero to 20 pounds per inch per minute. For rates from 20 to 200 pounds per inch per minute, the tensile strength increases, but no further increase is found for rates faster than this. The ultimate strength found by rapid loading is about 15 per cent. higher than that found for slow loading. It is therefore necessary to specify either a slow rate, below about 20 pounds per inch per minute, or a definite faster rate.

It is usual to test fabrics in a testing machine, similar to the Avery type shown in Fig. 119, p. 232 (Vol. I), in which *the rate of loading* can be varied to specification from 100 to 2000 pounds per minute. The usual rate of loading specified for linen fabrics is 150 pounds per inch width per minute.

The percentage stretch at breaking varies from 10 to 15 per cent. in linen fabrics and from 15 to 30 per cent. in rubbered balloon fabrics.

(*c*) *Tearing tests* should be prescribed, such that the force per unit width necessary to tear the fabric, when a small slit has been made in it, should not be less than a certain minimum value. It is useful to obtain the corresponding load-deflection curves for such tests.

(*d*) *Bursting tests* are usually made upon bags filled with air

* For definitions of these terms see p. 337.

or gas under pressure, or upon the material clamped over a metal container, so as to form a cover. Pressures and corresponding deflections are measured right up to the bursting points.

In general, the tensile test in warp and weft is usually sufficient for aeroplane coverings.

(*e*) *Permeability or Diffusion tests* should be made upon all fabrics intended for kite-balloons, dirigibles, and balloonet coverings; it is usual to specify a maximum rate of leaking for such fabrics. The permeability is commonly expressed in the number of litres of gas lost per square metre of surface per 24 hours.

Values of the permeabilities of various fabrics and coverings are given in Tables CXIV and CXXII.

The lowest rate of leakage obtainable for a rubber-proofed fabric is about 5 litres per square metre per 24 pounds, whilst for goldbeaters' skin* it is about 0·25 litres (for four layers) and 0·12 (for eight layers).

The permeability is found to increase after exposure to the action of sunlight and the weather.

## Action of Ultra-Violet Light.

It has been shown that when untreated linen or rubbered fabrics are exposed to the action of ultra-violet light (as when exposed to sunlight) that they deteriorate both in strength and gas-tightness; this effect is known as "ageing," and is more enhanced in the upper air layers where dust and moisture are absent.

The following tables show the deteriorating effects upon the strength and permeability of exposure to the action of the weather for definite periods.

* Goldbeaters' skins are membranes obtained from the mesentery of a cow, the piece obtained from one animal measuring about 8 × 20 inches. These skins are fixed to the fabric by glue or rubber solution, and varnished for protection against moisture.

## TABLE CXIII.

### Weathering Tests of Uncoloured Parallel-Doubled Rubbered Fabric.

| *Exposure in Months.* | *Tensile Strength (kilogrammes per metre width).* | | *Percentage Deterioration.* | | | *Percentage Contraction.* | | |
|---|---|---|---|---|---|---|---|---|
| | *Warp.* | *Weft.* | *Warp.* | *Weft.* | *Mean.* | *Warp.* | *Weft.* | *Mean.* |
| 1 | 1193 | 990 | −0·15 | 17·9 | 8·9 | 1·4 | 2·4 | 1·9 |
| 2 | 825 | 670 | 30·7 | 44·4 | 37·5 | 2·1 | 1·8 | 1·9 |
| 3 | 739 | 525 | 38·0 | 56·3 | 47·1 | 2·1 | 2·2 | 2·1 |
| 4 | 600 | 503 | 49·6 | 58·4 | 54·0 | — | — | — |

*Note.*—The initial warp and weft values were 1191 and 1206 kilogrammes per metre respectively.

## TABLE CXIV.

### Weathering Tests of Different Coverings.

| *Material.* | *Weight, grams per square metre.* | *Unweathered.* Leakage per sq metre per 24 hours in litres. | *Weathered.* Leakage per sq metre per 24 hours in litres. | *No. of Days.* |
|---|---|---|---|---|
| Parallel doubled, two layers of rubber, not coloured .. .. | 241 | 8·6 | Above 100 | 50 |
| Diagonally doubled, three layers of rubber, red rubber outside.. .. | 328 | 4·5 | Above 100 | 50 |
| Double Silk, varnished | 191 | 3·02 | 1·7 | 50 |
| Cotton, proofed .. | 284 | 13·5 | 8·78 and excessive | 50 |
| Goldbeaters' skin, 8 layers | 78 | 0·72 | 12 | 50 |
| Double Fabric, 1 layer rubber, yellow.. .. | 271 | 13·45 | 11·1 | 28 |
| Parallel doubled, 2 layers of rubber, yellow .. | 332 | 10·9 | 9·45 | 28 |
| Treble Fabric, yellow coated .. .. .. | 316 | 14·6 | 13·9 | 28 |

From Table CXIV it will be seen that the rubbered fabrics depreciate considerably in strength and in permeability, whereas the coloured rubbered fabric and the proofed cotton and silk coverings appear to improve in their non-leakage properties with time.

It is interesting to consider how the plain, unproofed fabrics behave after exposure to the weather for a certain period of time. The following are some results of weathering tests—

TABLE CXV.

| *Fabric.* | *Loss of strength after weathering for 50 days.* |
|---|---|
| Untreated pure net silk .. | 80 per cent. |
| Untreated finest quality linen | 45 ,, |
| Untreated finest quality cotton | 25 ,, |

## Effect of Doping upon Weathering Qualities.

The effect of doping and varnishing aeroplane fabrics is to considerably improve their ageing and strength qualities; a properly doped and varnished aeroplane linen fabric is from 20 to 25 per cent. stronger than the untreated fabric, and diminishes by from 10 to 16 per cent. in strength after a few months use.

Cellulose acetate dope coatings appear to be more affected by the weather than those of cellulose nitrate, due probably to the hygroscopic character of the former material, and to the ease with which waterproof materials are blended with the latter.

The quality of the dope used has a marked effect upon the ageing qualities, some dopes (such as solutions of cellulose esters) having a deteriorating effect.

## Treatment of Dirigible Fabric.

Rubbered balloon fabrics, which usually consist of cotton or linen, rubbered upon both sides or upon one side only, by

a process of vulcanization which causes the rubber to permeate the plies, are subject to the deteriorating effect of the ultra-violet rays of sunlight and moisture, so that it becomes necessary to protect them from this.

It is now customary to dye or coat the outer layers with a non-active pigment or material. Amongst the substances that can be used for this purpose are—

(1) *Lead Chromate*, a yellow compound which must be applied on the fabric before the layer of rubber ; the latter cannot, however, be vulcanized.

(2) *Picric Acid*, which possesses the disadvantage that it is highly poisonous.

(3) *Red or Yellow Aniline Dye*. The usual method is to dye the outer ply yellow or red, but it has been shown that, unless this ply is protected against moisture, it bleaches and leaves the material unprotected. It is considered more satisfactory to use an outer layer of proofing either of red or yellow to protect the ply from damp and sunlight.

(4) *Aluminium Paint or Powder*.—A fabric coated with fine aluminium reflects a good deal of the light from the surface (and incidentally the heat rays) and renders the material fairly water-proof ; this method has been used upon small airships.

(5) *Litharge, or Oxide of Lead*.—By embodying red lead in the rubber proofing, the latter can be made to withstand the effects of ultra-violet light for long periods.

(6) *Varnish*, such as *cellulose-ester lacquers*. The permeability improvement when a rubbered fabric is varnished amounts to about 50 per cent., and the weathering properties are considerably improved. Moreover, the fabric is protected against moisture, and the wind resistance greatly diminished. By blending oil with cellulose nitrate, a flexible coating for rubbered fabric can be obtained. The values given in Table CVII show the beneficial effects of varnishing.

(7) *Gelatine*. It has been found that a gelatined pigmented surface has a very low permeability ; for example, the

original permeability of a rubbered fabric was 11 litres per square metre per 24 hours, but when coated with a flexible gelatine compound it was 0·8 litres.

### Effect of Temperature upon Permeability.

It is known that the leakage of gas increases with the temperature. The following results* may be mentioned, to show the relative permeabilities of various fabrics at different temperatures—

TABLE CXVI.

EFFECT OF TEMPERATURE UPON PERMEABILITY.

| *Fabric or Material.* | *Temperature.* | *Permeability in litres per sq. metre per 24 hours.* |
|---|---|---|
| Diagonally doubled, 3 layers of Rubber | 15·5° | 6·71 |
| " " 3 " " | 22·1° | 10·84 |
| Parallel " 2 " " | 15·5° | 12·3 |
| " " 2 " " | 22·1° | 21·5 |
| Oilskin Fabric, 135 grams per sq. metre | 15·5° | 1·05 |
| " " 135 " " | 28·5° | 1·54 |
| " " 215·3 " " | 15·5° | 0·10 |
| " " 215·3 " " | 28·5° | 0·13 |

Goldbeaters' skin showed an increase of about 2 per cent. per degree C., that is to say, about one-quarter of that of the rubbered fabrics.

In the case of varnished silk, the permeability was *less* by about 3 per cent. per degree C.

### Absorption Tests.

All fabrics should show as low a moisture absorption as possible, and tests should be made by preliminary and final weighings after soaking the material in water for definite periods of time, and at fixed temperatures, or after exposure in a moist atmosphere. It is difficult to obtain consistent

* Report No. 6. Amer. Advis. Com. for Aeronautics, 1915.

results in tests of this kind, but the following results are approximately correct—

## TABLE CXVII.

### Moisture Absorption of Fabrics.

| *Material.* | *Moisture Absorption (Per cent. increase in weight after.)* | |
|---|---|---|
| | *Soaking in water.* | *Exposure to moist air.* |
| Single Rubbered Fabric .. .. | 38·4 | 38·2 |
| Parallel doubled, 2 layers of rubber, uncoloured .. .. .. .. | 41·9 | 35·7 |
| Diagonally doubled, 3 layers of rubber, red rubber outside .. .. .. | 34·6 | 36·9 |
| Trebled Fabric .. .. .. .. | 29·6 | 23·1 |
| Double silk, varnished .. .. | 16·9 | 9·3 |
| Goldbeaters' skin, 8 layers, strapped.. | 39·1 | 41·0 |
| Untreated Linen Fabric .. .. | 30–60 | 6–13 |

Tests* made upon aeroplane fabrics gave the following results—

(1) Compared with dried samples, fabrics exposed to the saturated atmosphere showed 6 to 13 per cent. of water, and in the normal atmosphere, from 3 to 7 per cent.

(2) Soaking causes the fabric to take up 30 to 60 per cent. of water.

(3) Cellulose acetate coatings suffer more from soaking than cellulose nitrate.

(4) Fabrics coated with rubber on one side and doped on the other side, show a smaller absorption of water on soaking, and a smaller increase in weight due to moisture taken up on standing in a saturated atmosphere, than unrubberized fabrics. The effect of varnish in preventing the absorption of water is very marked.

* Report No. 6. Amer. Advis. Com. for Aeronautics, 1915.

## FABRIC COMPONENTS AND TERMS

The following definitions refer to the threads or yarns of fabrics in general.

### Length of Yarn.

The length of a yarn is the length when the yarn is straight and is under no tension. In order to ascertain the length, the yarn is loaded in tension by equal increments and corresponding stretch readings are taken, the results being plotted as a graph. It has been found that after the fibres and the yarn have adjusted themselves the load-stretch curve becomes a straight line, and this portion of the curve is extended to intersect the zero-load co-ordinate; this length is taken to be the length of yarn under no tension. Fig. 96 shows a typical load-stretch curve for an unwoven yarn of coarse and multiple structure.

### Crimp.

This term is applied to the increased length of the yarn taken from the fabric over the length of the fabric itself. The difference is due to the interlacings of the yarns, and depends upon the size and count of the yarns. The crimp of the yarn governs, to a large extent, the stretch of the fabric under load.

### Yarn Count.

This is a measure of the size of the yarn, which is usually expressed in terms of length per unit of weight. For example, a No. 1 cotton yarn has 840 yards to 1 pound weight.

### Thread Count.

The thread count is the number of yarns per inch width of the fabric.

### Twist of Yarns.

This is ascertained by counting the number of turns necessary to untwist the yarn, the result being expressed in terms

of twist per unit length of the yarn, the length being taken as that of the initial untwisted yarn.

## AEROPLANE FABRICS

The fabrics now employed for aeroplane coverings are either of ramie, cotton, or linen.

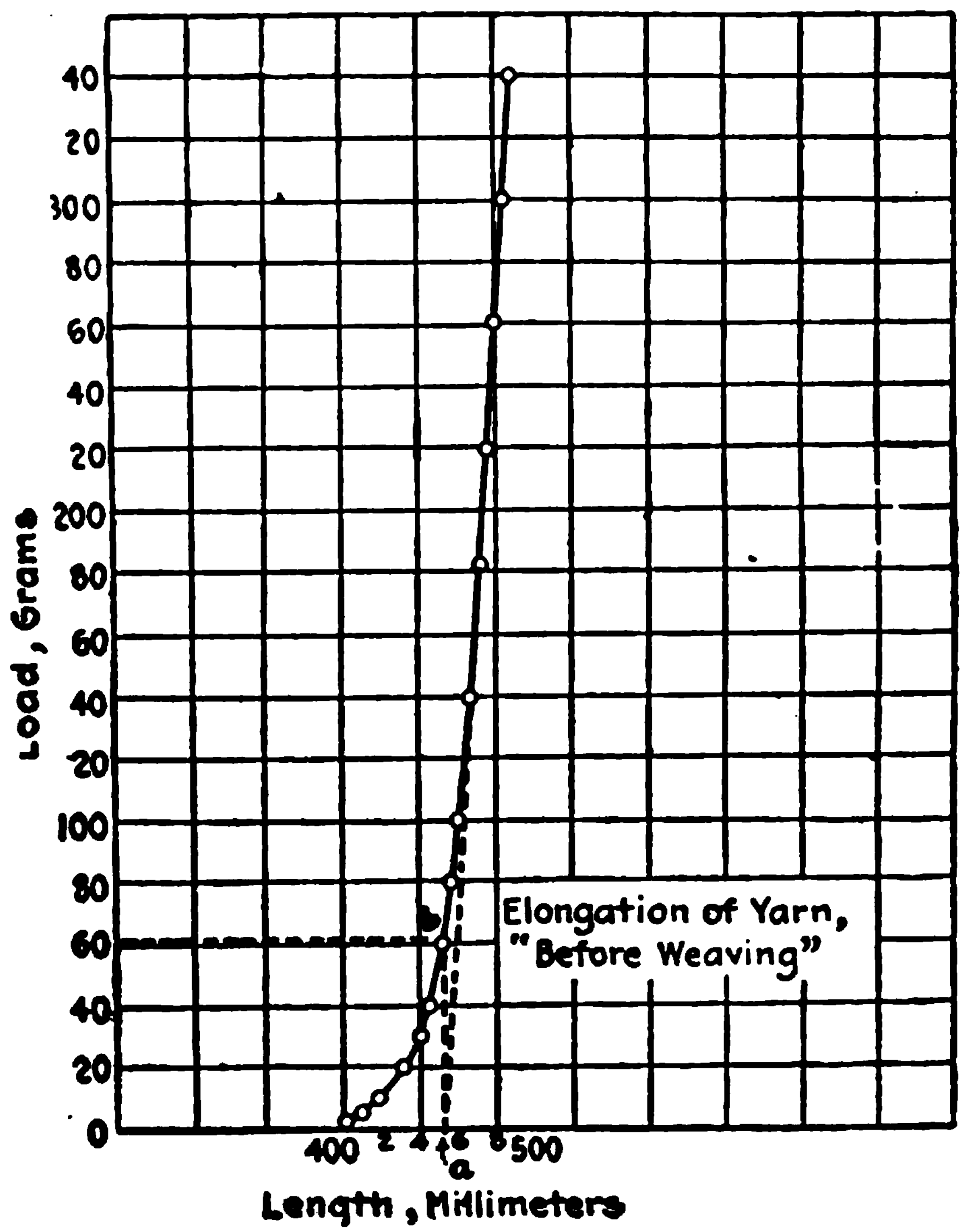



FIG. 96.—LOAD-STRETCH CURVE FOR UNWOVEN YARN.

Ramie is not much used, however, as it is difficult to obtain, and is not quite so strong as the linen fabric.

### Cotton Fabrics.

Cotton fabrics, chiefly of Egyptian cotton, have been used in the earlier types of machine, and in certain Continental

types,* but in general they possess a lower tensile strength for a given weight, and a lower tearing resistance than linen fabric, little shrinkage upon the application of dope, and they do not retain the shrinkage after doping.

Special cotton fabrics have, however, been evolved,† more especially during the late war, when linen fabrics became scarce, which closely approach, in their properties, those of linen fabrics. Figs. 97 and 98 show the load-stretch relations for Grade *A* linen, and Grade *A* cotton fabric as used upon modern machines.

The following table‡ shows how the tensile strength of cotton fabrics varies with the weight per square yard; it should be here explained that *warp* is the thread or yarn running lengthwise in the fabric, and *weft* (or "filler") is that running crosswise.

TABLE CXVIII.

WEIGHT AND STRENGTH OF COTTON FABRICS.

| *No.* | *Weight in ounces per square yard.* | *Tensile Strength (Pounds per inch width).* | |
|---|---|---|---|
| | | *Warp.* | *Weft.* |
| 1 | 1·60 | 27·0 | 26·0 |
| 2 | 1·85 | 24·3 | 24·5 |
| 3 | 1·98 | 31·0 | 31·0 |
| 4 | 2·44 | 41·5 | 49·0 |
| 5 | 2·67 | 40·9 | 49·2 |
| 6 | 3·51 | 70·0 | 67·0 |
| 7 | 3·86 | 72·0 | 75·0 |
| 8 | 4·05 | 84·0 | 78·0 |

Cotton fabrics are usually of single-ply yarns, the number of threads varying from 120 to 144 per inch, depending upon the weight and the strength.

* German machines during the war employed colour-printed or camouflaged cotton fabric.

† "Properties of Airplane Fabrics," E. Dean Walden. *Aviation*, 15th Dec., 1918.

‡ Report No. 6. Amer. Advis. Com. for Aeronautics, 1915.

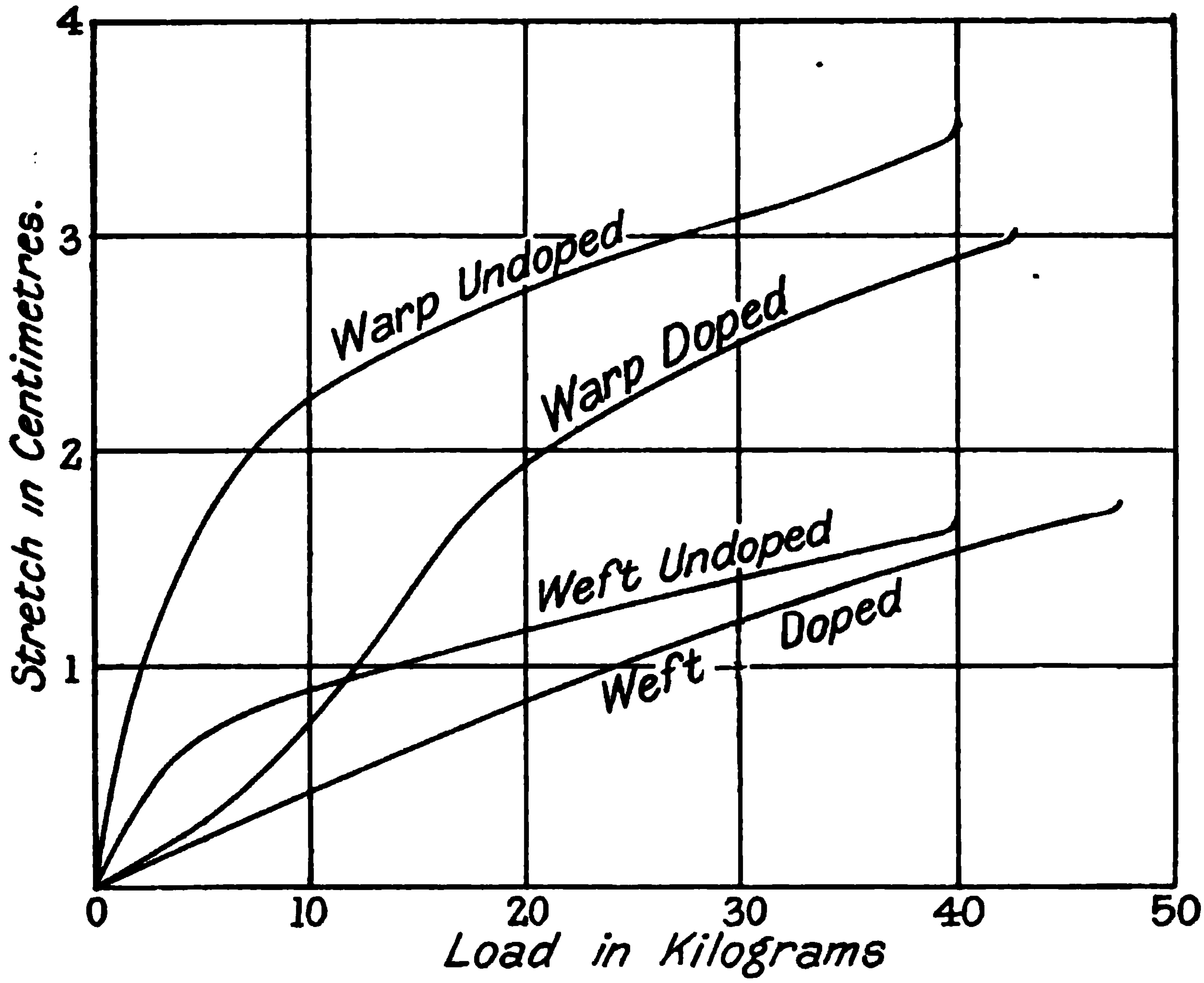



FIG. 97.—LOAD-STRETCH CURVES FOR LINEN FABRIC.

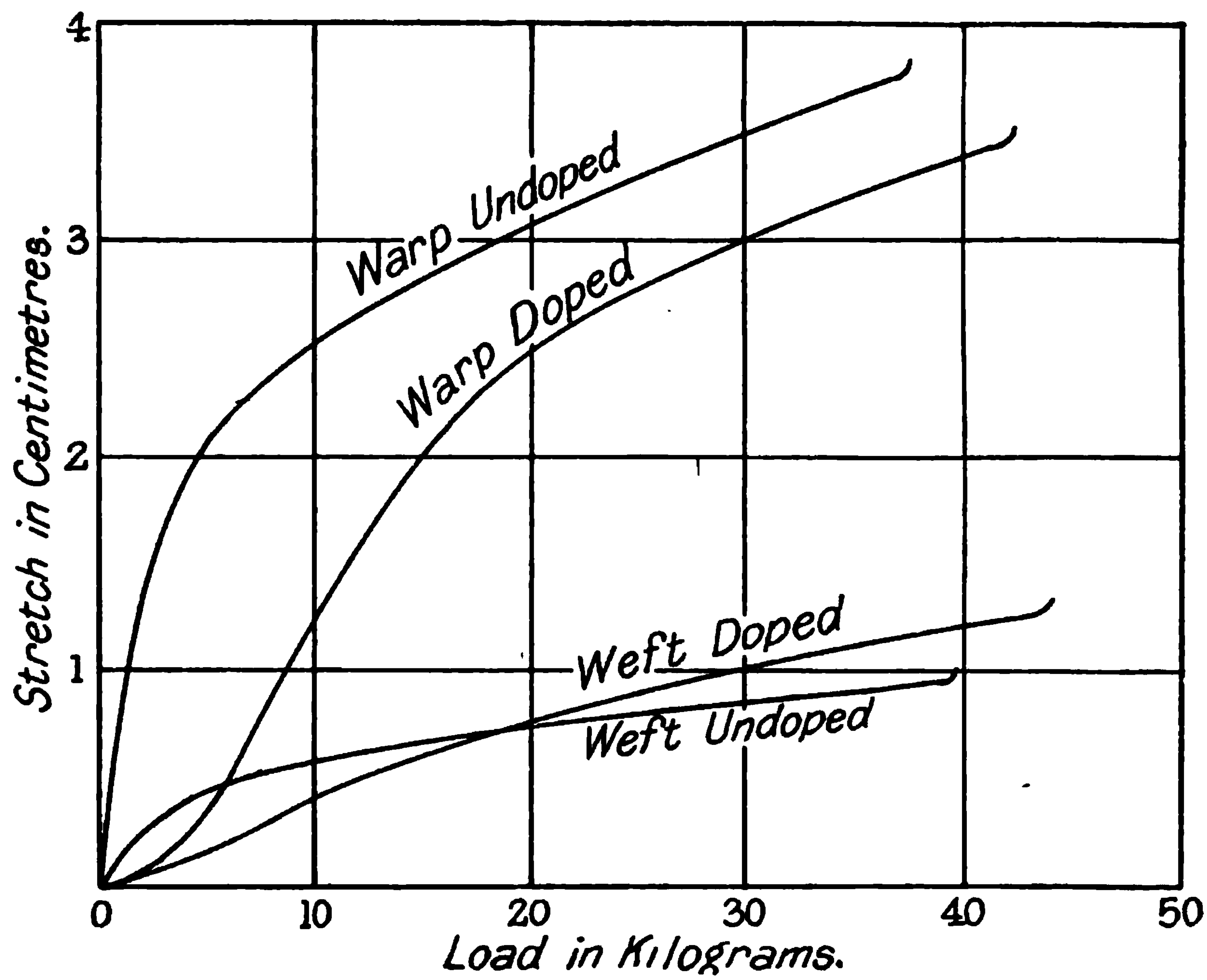



FIG. 98.—LOAD-STRETCH CURVES FOR COTTON FABRIC.

For aircraft purposes, cotton fabrics are of approximately equal strength in both warp and weft, whereas for most other purposes, such as for clothing, the strength is much greater in the warp.

The fabric used upon Farman aeroplanes* was a cotton one, weighing about 4½ ounces per square yard, and having a tensile strength of from 80 to 90 pounds per inch width; the number of picks and ends were respectively 120 and 115.

Ordinary cotton fabrics which have been used upon aeroplanes in recent times have a tensile strength in warp of from 50 to 80 and in weft of from 56 to 90 pounds per inch, with an extension of from 12 to 20 per cent. The effect of doping such fabrics is to increase their strength by from 20 to 30 per cent.

The weight of aeroplane cotton fabrics varies from about 3·5 to 5·0 ounces per square yard undoped, and from about 4·3 to 6·5 ounces per square yard (for 4 coats of dope and 1 coat varnish). Owing to the finer weave and nap surface of cotton fabrics they are less affected by moisture than linen fabrics, the yarn of which is more like wire.

Cotton fabrics have, in the undoped state, a higher surface resistance by from 10 to 15 per cent., for the same reason as that given in the last paragraph, but in the doped and varnished state there is no difference between cotton and linen fabrics.

Cotton fabrics, in general, require rather more dope than linen fabrics, and show a somewhat greater tendency to become slack after exposure for long periods; they do not, however, show any appreciable differences from linen in their ageing or weathering properties.

## International Aircraft Standard Specifications for Cotton Fabrics.

There are two types or grades of cotton fabrics specified, known as Grade *A* and Grade *B* respectively, each in the mercerized and

* 1913 to 1916.

unmercerized conditions. The specifications for Grade *A* only are given; those for Grade *B* exactly resemble these, except that*—

(*a*) The single yarn must be given 36 to 40 turns per inch of twist, and that 18 to 20 turns per inch must be used for twisting these yarns together.

(*b*) There must be at least 68 threads and not more than 72 threads per inch in both warp and filling (or weft).

(*c*) The weight under normal moisture conditions must not weigh more than 4 ounces per square yard.

(*d*) The average results for both warp and filling should be as follows—

| *Tension in pounds.* | *Elongation in inches.* | |
|---|---|---|
| | *Warp.* | *Filling.* |
| 10 | 0·70 | 0·44 |
| 20 | 0·86 | 0·52 |
| 65 | 1·19 | 0·78 |

(*e*) In the *unmercerized cotton fabric, Grade B,* it is recommended that the single yarn be given 36 to 40 turns per inch of twist, and that 18 to 20 turns per inch be used for twisting these yarns together.

(*f*) There must be at least 68 and not more than 72 threads per inch in both warp and filling.

(*g*) The fabric, under normal moisture conditions, must not weigh more than 4·2 ounces per square yard.

(*h*) The average results for both warp and filling should be as follows—

| *Tension in pounds.* | *Elongation in inches.* | |
|---|---|---|
| | *Warp.* | *Filling.* |
| 10 | 0·84 | 0·68 |
| 20 | 1·06 | 0·84 |
| 65 | 1·53 | 1·24 |

## Specifications for Mercerized Cotton Aeroplane Fabric (Grade *A*).

(2*F*1, *April,* 1918.)

1. General.—The general specifications, 1G1, shall form, according to their applicability, a part of these specifications.

2. Material.—(*a*) The warp and filling yarns used in the manufacture of this fabric must be size 2/60, according to the English cotton yarn numbers. A tolerance of plus or minus four (± 4) will be allowed in the size of single yarns.

* For the mercerized condition.

(*b*) The length of the staple of the fabric must not be less than 1¼ inches.

3. Manufacture.—(*a*) The yarn shall be combed (single or double) and shall be mercerized under tension.

(*b*) It is recommended that the single yarn be given 28 to 34 turns per inch of twist and that 16 turns per inch be used for twisting these yarns together. This procedure may be altered provided that the fabric conforms to this specification in other respects.

(*c*) There must be at least 80 threads and not more than 84 threads per inch in both warp and filling.

(*d*) The weave shall be plain weave.

(*e*) The fabric must be uniform in structure and free from manufacturing imperfections.

(*f*) The fabric, under normal moisture conditions, must not weigh more than 4·5 ounces per square yard.

(*g*) The width must be 36 inches.

4. Physical Properties and Tests.—*Tensile Test.* (*a*) The tensile test specimens, prepared in accordance with paragraphs 5 (*a*), 5 (*b*), and 5 (*c*), shall be exposed for at least two hours in an atmosphere of 65 per cent. relative humidity at 70° F. (21° C.), and then tested in this atmosphere.

(*b*) The distance between the jaws or clamps of the testing machine at the beginning of the test shall be 8 inches (20 centimetres). The pulling jaw shall move at the rate of 12 inches per minute during the test.

(*c*) The average breaking load of the five specimens cut in the direction of the warp and the average breaking load of the five specimens cut in the direction of the filling, as shown in Fig. 99, must each be at least 80 pounds.

(*d*) The elongation shall be observed when the specimens are subjected to each of the loads given in Table I.

(*e*) Whenever practicable, an autographic record shall be taken.

(*f*) The elongation must not exceed the values given in Table I by more than 10 per cent.

(*g*) The average results for both warp and filling shall be reported separately.

TABLE I.

| *Tension in pounds.* | *Elongation in inches.* | |
|---|---|---|
| | *Warp.* | *Filling.* |
| 10 | 0·65 | 0·32 |
| 20 | ·80 | ·40 |
| 70 | 1·20 | ·64 |

*Test for Sizing.* (*h*) Tests for sizing shall be conducted as follows—

(1) Dry samples weighing approximately 0·18 ounce (5 grams) in tared weighing bottles at 221 to 230° F. (105 to 110° C.) to constant weight.

(2) Boil the samples in water for 10 minutes and rinse thoroughly.

(3) Digest each sample in a solution containing 15 centimetres commercial diastofor in 500 centimetres water at 140° F. (60° C.) for 2 hours.

(4) Wash thoroughly in hot water and then boil for 1 hour in 500 centimetres distilled water and wash again.

(5) Dry in tared weighing bottles to constant weight.

(6) Percentage sizing $= \dfrac{\text{loss in weight}}{\text{original weight}} \times 100.$

(*i*) The fabric must not contain more than 3·5 per cent. of sizing, as determined by the above method.

*Mercerization Tests.*—(*j*) Take approximately $\frac{1}{4}$ square foot of the cloth, immerse in boiling distilled water and stir occasionally while cooling. At the end of 10 minutes place a strip of blue and a strip of red litmus paper into the liquid with the fabric and allow them to remain 5 minutes. At the end of this time the litmus papers must

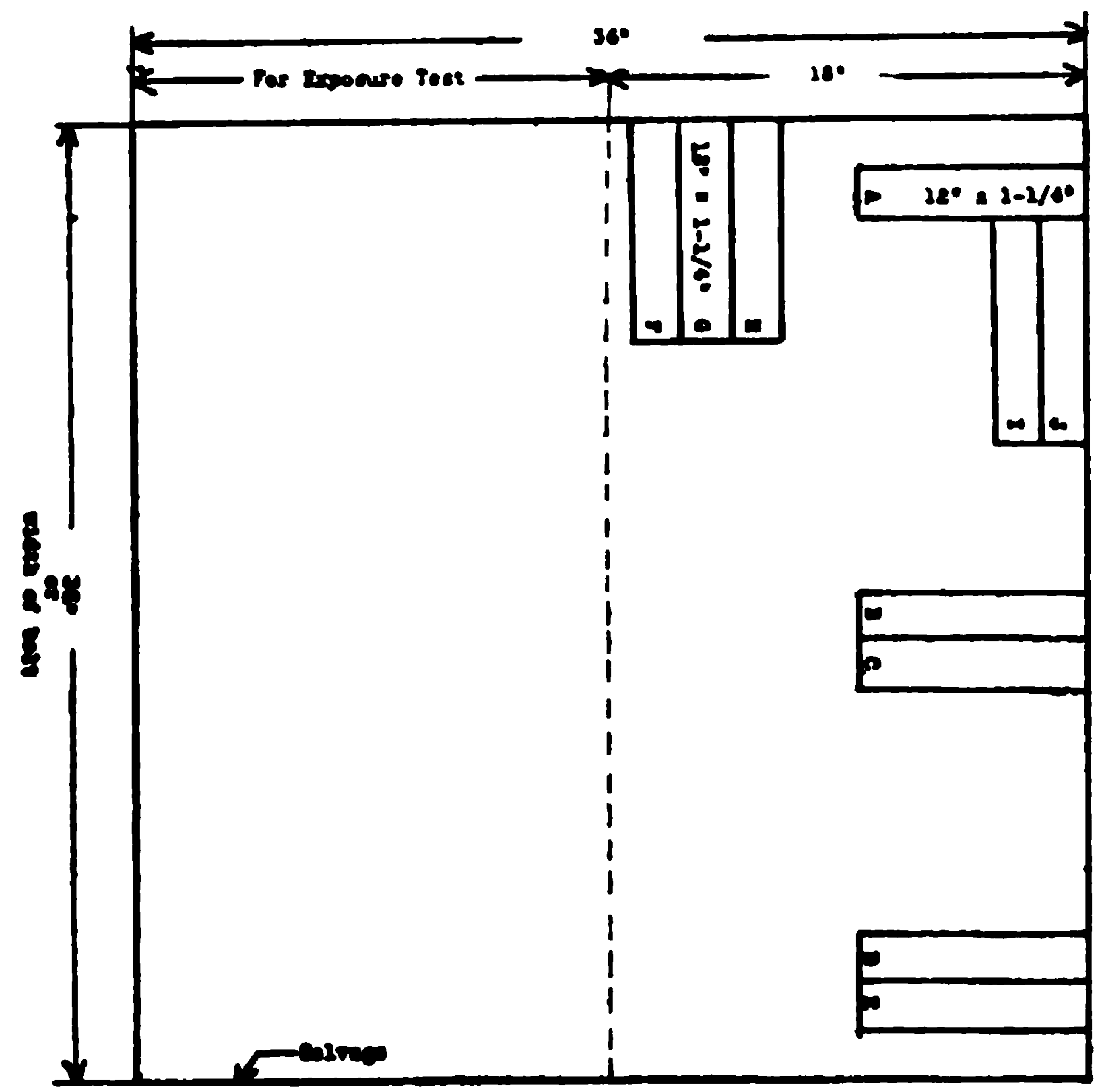



FIG. 98.—SKETCH SHOWING THE LOCATION OF THE TEN TEST SPECIMENS (LETTERED *A* TO *F*) TO BE CUT FROM THE SAMPLE.

have retained their original colours. Any cloth showing either an acid or alkaline reaction shall be rejected. This test may be made on the yarn before weaving by substituting a small handful of the yarn for the cloth sample.

5. SELECTION OF TEST SPECIMENS.—(*a*) Samples for tests shall be taken from at least five bolts in each warp woven.

(*b*) The sample taken from a bolt shall be 1 yard long and the full width of the bolt; it shall be cut from the fabric at a point 10 yards from the end of the bolt.

(*c*) Test specimens for tensile test, 12 inches long and $1\frac{1}{4}$ inches wide, hall be cut from each sample taken as shown in Fig. 98. Threads

shall be pulled out from the sides of the test specimens until a width of 1 inch of woven fabric remains.

6. INSPECTION AND REJECTION.—The inspector shall mark all accepted material close to the end of each bolt with the official acceptance stamp. Rejected material shall be marked with the rejection stamp and shall not be re-submitted without the express consent of the purchaser. The acceptance and rejection stamps shall be so placed that they do not injure the material, or, in the case of rejected fabric, so that the marking does not preclude the use of the material for other than aircraft work.

7. REPLACEMENTS.—All fabric that does not conform to this specification shall be rejected and shall be replaced by the manufacturer at his expense.

## SPECIFICATIONS FOR UNMERCERIZED COTTON AEROPLANE FABRIC (GRADE *A*).

(2*F*2, *April*, 1918.)

1. GENERAL.—The general specifications, 1G1, shall form, according to their applicability, a part of these specifications.

2. MATERIAL.—(*a*) The warp and filling yarns used in the manufacture of this fabric must be size 2/60, according to the English cotton-yarn numbers. A tolerance of plus or minus four ($\pm$ 4) will be allowed in the size of single yarns.

(*b*) The length of the staple of the fabric must not be less than 1¼ inches.

3. MANUFACTURE.—(*a*) The yarn shall be combed (single or double).

(*b*) It is recommended that single yarn be given 22 to 25 turns per inch of twist and that 25 to 26 turns per inch be used for twisting this yarn together. This procedure may be altered provided that the fabric conforms to this specification in other respects.

(*c*) There must be at least 93 threads per inch in warp and 86 threads per inch in filling. A tolerance of plus or minus two ($\pm$ 2) threads will be allowed.

(*d*) The weave shall be a plain weave.

(*e*) The fabric must be uniform in structure and free from manufacturing imperfections.

(*f*) The fabric, under normal moisture conditions, must not weigh more than 4·5 ounces per square yard.

(*g*) The width must be 36 inches.

4. PHYSICAL PROPERTIES AND TESTS.—*Tensile Test.* (*a*) The tensile test specimens, prepared in accordance with paragraphs 5 (*a*), 5 (*b*), and 5 (*c*), shall be exposed for at least 2 hours in an atmosphere of 65 per cent. relative humidity at 70° F. (21° C.) and then tested in this atmosphere.

(*b*) The distance between the jaws or clamps of the testing machine at the beginning of the test shall be 8 inches (20 centimetres). The pulling jaw shall move at the rate of 12 inches (30 centimetres) per minute during the test.

(*c*) The average breaking load of five specimens cut in the direction of the warp and the average breaking load of the five specimens cut in the direction of the filling, as shown in Fig. 99, must each be at least 75 pounds.

(*d*) The elongation shall be observed when the specimens are subjected to each of the loads given in Table II.

(*e*) Whenever practicable an autographic record shall be taken.

(*f*) The elongation must not exceed the values given in Table II by more than 10 per cent.

(*g*) The average results for both warp and filling shall be reported separately.

TABLE II.

| *Tension in pounds.* | *Elongation in inches.* | |
|---|---|---|
| | *Warp.* | *Filling.* |
| 10 | 0·74 | 0·42 |
| 20 | ·94 | ·53 |
| 70 | 1·44 | ·90 |

*Test for Sizing.*—(*h*) Tests for sizing shall be conducted as follows—

(1) Dry samples weighing approximately 0·18 ounce (5 grams) in tared weighing bottles at 221 to 230° F. (105 to 110° C.) to constant weight.

(2) Boil the samples in water for 10 minutes and rinse thoroughly.

(3) Digest each sample in a solution containing 15 cubic centimetres commercial diastofor in 500 cubic centimetres water at 140° F. (60° C.) for two hours.

(4) Wash thoroughly in hot water and then boil for 1 hour in 500 cubic centimetres distilled water and wash again.

(5) Dry in tared weighing bottles to constant weight.

(6) Percentage sizing $= \frac{\text{loss in weight}}{\text{original weight}} \times 100.$

(*i*) The fabric must not contain more than 3·5 per cent. of sizing, as determined by the above method.

5. Selection of Test Specimens.—(*a*) Samples for tests shall be taken from at least five bolts in each warp woven.

(*b*) The sample taken from a bolt shall be 1 yard long and the full width of the bolt; it shall be cut from the fabric at a point 10 yards from the end of the bolt.

(*c*) Test specimens for tensile tests, 12 inches long and 1¼ inches wide, shall be cut from each sample taken, as shown in Fig. 1. Threads shall be pulled out from the sides of the test specimens until a width of 1 inch of woven fabric remains.

## Linen Fabrics.

Linen fabrics made from closely woven Courtrai or Irish flax have been very widely used, in the unbleached state, for aeroplane wing, control, and fuselage coverings; the yarns are usually spun wet with a moderate amount of twist.

Linen fabrics in general weigh from 3½ to 6 ounces per square yard, the heavier grades being used for flying boats and seaplanes; the normal type of aeroplane linen fabric should not, however, exceed about 4 ounces per square yard

in the undoped state. The Belgian or Courtrai flax is the finest in quality, Irish comes next, then the Dutch, and finally the coarser Russian flax.

The tensile strength of linen fabric varies somewhat with the weight, the following being average values—

TABLE CXIX.

TENSILE STRENGTH OF LINEN FABRICS.

(American Advisory Committee for Aeron. Report, 1915.)

| *No.* | *Weight in ounces per square yard.* | *Tensile Strength in pounds per inch.* | |
|---|---|---|---|
| | | *Warp.* | *Weft.* |
| 1 | 3·67 | 65 | 54·4 |
| 2 | 3·78 | 69·5 | 49·2 |
| 3 | 3·87 | 80·7 | 79·0 |
| 4 | 4·04 | 86·9 | 74·0 |
| 5 | 4·09 | 90·2 | 82·7 |
| 6 | 4·48 | 82·9 | 100·1 |
| 7 | 4·60 | 95·0 | 60·0 |
| 8 | 4·86 | 90·4 | 102·5 |

The above values are somewhat lower than those obtained from higher grade aeroplane fabrics, which are usually specified for the 4 ounces per square yard grade to have a minimum tensile strength of 90 and 100 pounds per square inch in warp and weft respectively, when loaded at the rate of 150 pounds per inch width per minute.

The tensile strength varies with the percentage of moisture, for undoped cotton and linen fabrics, and to a lesser extent for single-side doped fabrics, the strength increasing with increased moisture content.* It is now usual to test the fabric in the wet state, or to prescribe the humidity of the atmosphere in which the sample is tested.

The stretch or elongation of linen fabric at the breaking load varies from about 5 to 10 per cent. for low grades and

* There is a difference of from 10 to 20 per cent. in the strength of wet and dry fabric.

from 10 to 20 per cent. for high grades; the effect of doping and varnishing is to somewhat increase the percentage stretch.

Figs. 97 and 98 show the relation between the load and

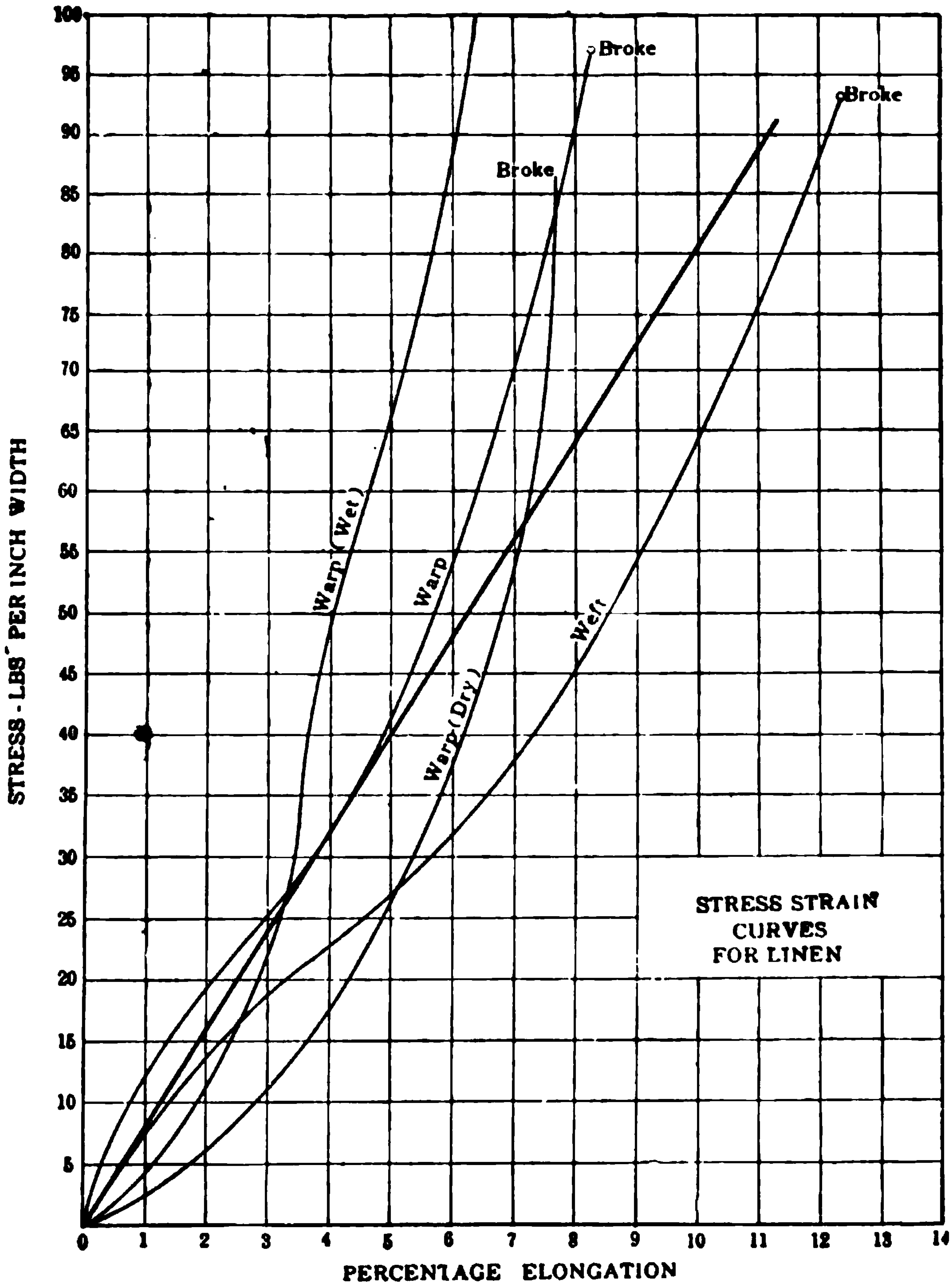



FIG. 100.—LOAD-STRETCH CURVES FOR MOIST AND DRY LINEN.

stretch of linen and cotton fabrics respectively, and Fig. 100 shows the same relation for wet and dry linen fabrics of different grades.

In general, it will be seen that at first the rate of stretch

is slow for doped fabrics, up to 10 or 20 pounds load, after which it rises more rapidly.

For uncoated fabrics the opposite state of affairs appears to exist, there being a considerable initial stretch under light loads up to about 20 pounds, then the "slack" having been removed from the fibre, the rate of stretch is much slower. The total stretch of the undoped fabric will be seen to be appreciably less than that of the doped.

For aeroplane covering purposes, the number of *ends* per inch should be between 90 and 100, and the number of *picks* per inch between 95 and 105.

**Tearing Test Results.**

The lower grade of linen is more difficult to tear than the higher grades, probably because the higher grade fabrics, both linen and cotton, owe their greater strength for a given weight to a greater number of threads or yarns per inch. These yarns are smaller in diameter, and since the tearing effect chiefly depends upon the strength of the individual threads, the closely woven fabrics are the weaker in tearing. When the weaves are loose the tearing quality is improved, and the simple under-and-over fabric continues to tear more easily than a full weave. When, however, the loose-weaves are doped, there is not much difference in the tearing effect; the net-weave class of fabric resists tearing better because of its ability to distort until a number of ends or picks simultaneously come under the *V* of the notch or tear.

The process of weaving strong threads at intervals in directions at right angles so as to break the fabric up into a number of squares, is to greatly increase its resistance to tearing. Such fabrics are, however, heavier and offer more surface resistance.

**Thread Testing Machines.**

Figs. 101 and 102 show two alternative types of tensile testing machine for ascertaining the strength of threads and

fibres. In the former diagram the thread is held in a vertical position, the machine parts being bolted to a wall or beam.

FIG. 101.—TESTING MACHINE FOR FIBRES, THREADS, ETC.

The yarn or thread is passed over the loop on the beam and both ends are secured to the lower piece *A* by winding several times around the hook. Pressure is applied by means of

the hand-wheel C, actuating a screw thread, and the pull is balanced on the yard-arm by means of the sliding weight shown. The beam is graduated to read loads off directly, and these loads must be halved for the single thread load values. The machine illustrated has a maximum capacity of 20 pounds.

FIG. 102.—THE BAILEY FIBRE AND THREAD TESTING MACHINE.

The machine shown in Fig 102 is of the horizontal pendulum type, the load being applied by means of a worm and worm-wheel operated screw and measured by means of a pendulum operated dial lever system, which gives readings proportional to the angular displacement of the pendulum, which are in turn proportional to the loads on the threads, fibres, or yarns. The machine illustrated is made in the 250 pounds and 500 pounds capacity sizes.

**Fabric Testing Machines.**

The Avery fabric and textile material testing machine is fully described on p. 232 of Vol. I.

Fig. 103 shows in outline the principle of another form of machine* used for stress-strain or load-stretch measurements upon fabrics and similar materials; this apparatus is also

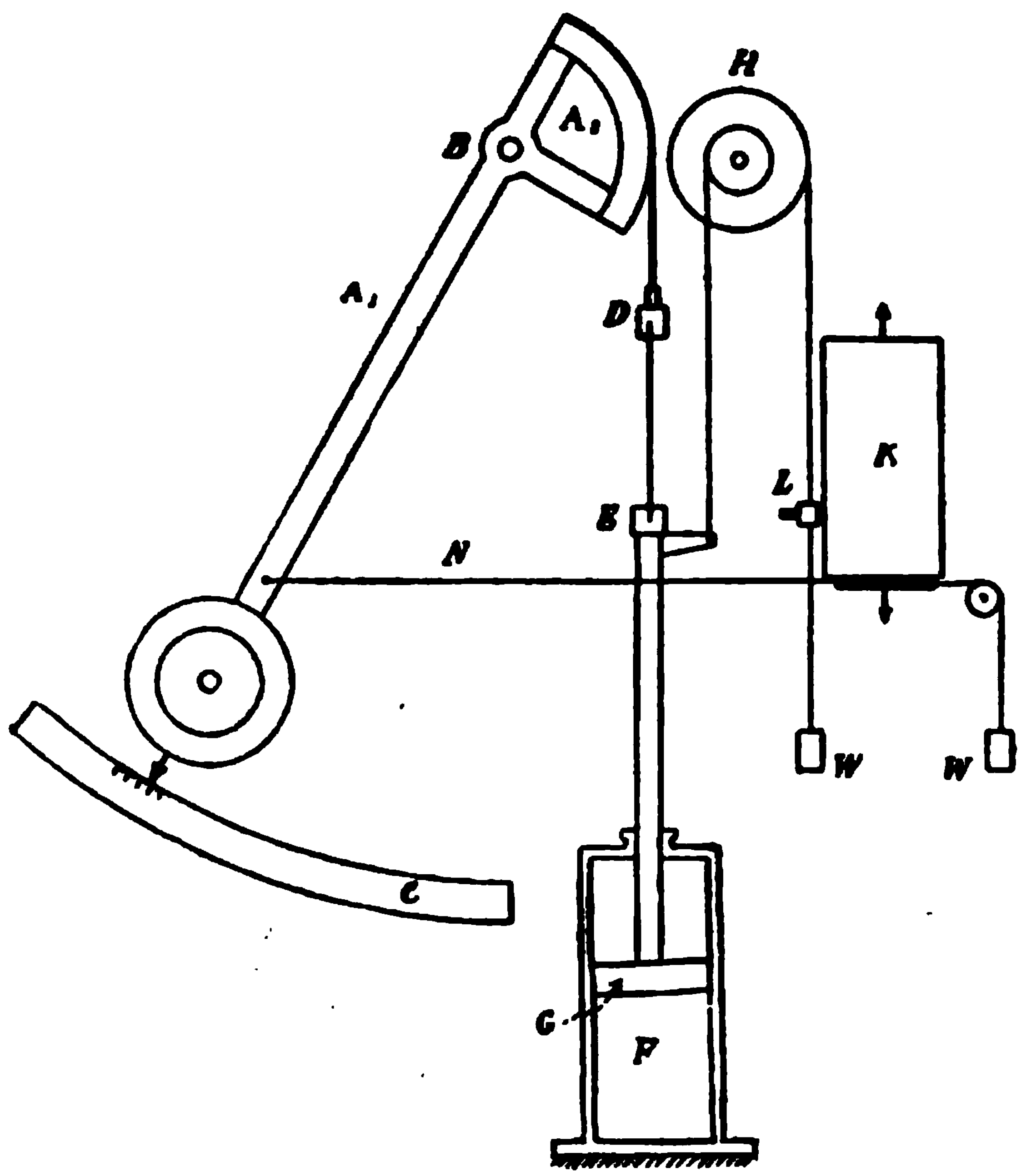



FIG. 103.

very convenient for making autographic records of load and stretch.

The fabric is indicated by the line *DE*, at one end (*E*) of which the load is applied by means of a hydraulic piston *G*, in a cylinder *F*. The other end (*D*) is attached to a pendulum lever quadrant pivoted at *B*, the angular displacements of which are proportional to the load applied to the specimen

* Described in "Properties of Aeroplane Fabrics," E. Dean Walden, Amer. Soc. Mech. Engrs., Dec. 1918.

*DE*; these can be read off on the scale *C*. The autographic apparatus is shown at K, and consists of a cylindrical drum *K*, which is rotated by means of a cord *N* attached to the pendulum *A*, the rotation being proportional to the load applied. The stretch is recorded on the drum *K* by means of a pencil L, which is attached to a string passing over a pulley H, which is rotated directly by means of a string from the specimen cross-head E; in this way the pencil movement is greater in the ratio of the pulley diameters than the actual stretch.

Fig. 104 illustrates the Olsen textile testing machine for testing materials such as cloth, leather, fabric, paper, twine, gut, packing, and insulating materials.

The material to be tested is held between two clamps, and the load is applied by means of the hand-wheel shown near the base of the instrument.

The amount of the load is indicated upon the graduated dial, which has a range of 200 pounds in the type shown.

Fig. 104.—The Olsen Textile Testing Machine.

A taper wedge is used to follow the downward motion of the spring in the balance, and holds the spring extended at the breaking load of the specimen until released by the horizontal hand-lever shown in Fig. 104. The grips in the machine are exactly 1 inch wide, and it is recommended that in textile testing the

specimen should be cut at least 2 inches wide, so that, when placed in the jaws, the test is on 1 inch width in the body of the cloth.

Paper should be cut in strips of 1 inch width.

Fig. 105 shows a more elaborate form of vertical testing machine, intended for long specimens of rope, cord, rubber, fabric, and similar materials. The cross-head is screw-operated, and the load is weighed or measured on a scale arm provided with a jockey weight.

The load can be applied at a uniform rate by means of the electric motor shown, driving through a train of gears to the cross-head.

An autographic load-stretch apparatus is provided with this machine.

FIG. 105.

**Weathering Tests of Linen Fabrics.**

Some interesting tests were carried out by the N.P.L.

Authorities* upon linen fabric in the undoped and doped conditions, and upon samples of doped fabric which had been in use for a period of 7 months upon an aeroplane.

The mean results of these tests, which are given in Table CXX, show that the resistance of doped fabric to weathering is very good, and that the strength at the end of seven months' use upon the tail plane of an aeroplane is still very high, while the total extensibility is practically unchanged; at low stresses the extension is much greater than for the new doped fabric, showing that the dope layers have deteriorated.

In connexion with other tests made upon different fabrics, it was found that there was a considerable variation in individual results for the same fabric, and that for the same stress value there is a marked difference in the elongations of different fabrics.

In connexion with the tests of doped fabrics, it was found that the doping increased the tensile strength by 25 per cent., whilst the extensibility was diminished, for the same loads, by 17 to 18½ per cent.; for example, in one case the extension at a load of 250 kilogrammes in the undoped fabric was 12·5 per cent., whereas for the doped fabrics it varied from 4½ to 7 per cent.

## Surface Friction of Linen Fabrics.

Tests made by the American Advisory Committee for Aeronautics in 1915 showed that the surface resistance of high grade linen fabric was about 36 per cent. greater than that of plate glass; whilst for the same linen with one coat of dope it was 16 per cent. greater.

When the linen was doped with three coats, and afterwards varnished, the surface friction was found to be only from 6 to 8 per cent. higher than that of plate glass.

* "Experiments on Aeroplane Fabrics," Report No. 90. Jan., 1913. Advis. Com. of Aeronautics.

# TABLE CXX.

## Weathering Tests of Linen Fabrics.

| Material. | Tensile Strength after a period of | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 days. | | 21 days. | | 30·5 days. | | 40·5 days. | | 53·5 days. | |
| | Pounds per Inch | Kgs. per Metre | Pounds per Inch | [illegible] | [illegible] | Kgs. per Metre | Pounds per Inch | Kgs. per Metre | Pounds per Inch | Kgs. per Metre |
| 1. Untreated linen fabric (106·1 grams per square metre).. | 56·2 | 1003 | 33·2 | [illegible] | [illegible] | 656 | 30·8 | 551 | — | — |
| 2. Same fabric treated with 4 thin coats of Emaillite Dope No. 2, and 3 coats of Emaillite Dope No. 3 (161·5 grams per square metre) .. | 70·5 | 1258 | 44·3 | 791 | 41·1 | 733 | 38·5 | 687 | 34·9 | 624 |
| 3. Same linen treated as in (2) which had been in use for 7 months on tail plane of B.E. 2 aeroplane (148·5 grams per square metre).. | 61·3 | 1094 | 44·9 | 802 | 41·1 | 734 | 40·3 | 720 | — | — |

The resistance of doped and varnished fabric can be expressed in the following manner—

$$R = \cdot 0000153\, V^{1 \cdot 85}$$

where R = the resistance in pounds per square foot (single surface) at V M.P.H.

Biassed fabrics and those with nap on the surface show a higher resistance than linen fabric ; cotton fabrics also show a higher surface friction for this reason.

**Pressures upon Aeroplane Fabrics.**

The pressures experienced by the fabric upon aeroplane wings in flight are negative for the upper surface (that is, a suction) and positive for the under surface.

The average suction experienced by the upper surface is about 3 to 5 times the value of the positive pressure on the lower surface, and in the case of wing sections flying at from $\frac{1}{2}°$ to 3° incidence, practically all of the load comes upon the upper surface of the wing.

The average wing surface loadings of modern aeroplanes vary from about 5 to 9 pounds per square foot, but the maximum loading (owing to the fact that the pressure intensity is greatest near the leading edge*) may attain a value of 20 to 30 pounds per square foot (negative).

Under exceptional conditions of flying, that is, during "stunting," the maximum pressures may be considerably higher. For example, in the case of an aeroplane flying normally at 70 M.P.H., the maximum negative pressure (suction) would be from 20 to 25 pounds per square foot, and the mean value 5 to 6 pounds per square foot. ; when the machine is dived at 100 M.P.H. and then flattened out with an angle of incidence of from 10° to 12°, the value of the maximum negative pressure will be about 100 pounds per square foot.

* For fuller particulars of the pressure distributions over aeroplane wings, see "Properties of Aerofoils and Aerodynamic Bodies," A. W. Judge (Pitman).

The following results* show the negative pressures experienced by an aeroplane wing under normal and abnormal conditions of flying—

PRESSURES UPON THE UPPER SURFACES OF AEROPLANE WINGS.

| *Distance from leading edge in terms of chord.* | *Abnormal Conditions.* | | *Normal Conditions.* | |
|---|---|---|---|---|
| | *Pressure per sq. ft. on fabric in pounds.* | *Pounds per inch run on ribs.* | *Pressure per sq. ft. on fabric in pounds.* | *Pounds per inch run on ribs.* |
| 0·0 | 102 | 7·8 | 25 | 1·9 |
| 0·1 | 87 | 6·7 | 27 | 2·1 |
| 0·2 | 66 | 5·5 | 27 | 2·1 |
| 0·3 | 56 | 4·3 | 27 | 2·1 |
| 0·4 | 51 | 3·9 | 25 | 1·9 |
| 0·5 | 41 | 3·1 | 21 | 1·6 |

*Note.*—The rib spacing is taken as 0·92 foot, and the whole air pressure is taken by a single layer of fabric.

In passing, it may be mentioned that the intensity of positive or negative pressure is always a maximum where the radius of curvature of the surface is a minimum ; for this reason the leading edge portion of wings, and the nose-portions of streamlined bodies, experience the highest pressure effects.

## Working Tensions in Aeroplane Fabrics.

The tension in the fabric of an aeroplane wing or plane depends upon the pressure or suction to which it is subjected, and this in turn depends upon the shape of the section and the relative speed of the air over the surface. The tension will also be influenced by the spacing of the ribs or formers and by the relation of this spacing to the chord length ; it will also be increased by the amount of the initial stretching and doping tension.

The form assumed by the fabric between two wing ribs is

* Report No. 84., Dec., 1912. Advis. Com. for Aeronautics.

very nearly that of a parabolic curve, and the height $H$ of the centre or vertex of the curve above the ribs is given by*—

$$H^2 = \frac{3TS^2}{6400} \text{ inches}^2$$

where $T$ = the tension in the linen due to air pressure or suction, in pounds per inch width

and $S$ = distance between the ribs in inches.

If $w$ = the loading over the span per inch width, then

$$H = \frac{S}{8}\sqrt[3]{\frac{3w}{100}}$$

These relations fix the maximum permissible amount of "hog" or "sag" in the fabric.

Under the worst conditions of flight, namely, a dive at 150 M.P.H., the maximum suction near the leading edge would be about 300 pounds per square foot, or 2·08 pounds per square inch, and the corresponding tension about 35 pounds per inch width, with a "hog" $H$ of about 1·85 inches.

Using fabric of 96 pounds per inch width would give a factor of safety of about 2·7.

The above fabric stresses are excessive, and would not be realized in ordinary manoeuvring, but the results are interesting in showing that ordinary fabrics can withstand any working tensions due to abnormal flying conditions, with a satisfactory margin of safety.

The maximum working tension in the fabric at the usual flying speeds is about 10 to 15 pounds per inch run, and this allows a factor of safety of from 6 to 9½ or more.

The following expression† also shows the relation between the tension and the air pressure, namely—

$$t = \text{P. S.}\sqrt{\frac{1}{24\,e}}$$

* "Materials in Airplane Construction, N. L. Liebermann. *Aviation*, 15th June, 1917.

† "The Stresses in the Fabric, etc., of an Aeroplane Wing," Report 84, Dec., 1912. Advis. Com. for Aeronautics.

where $t$ = tension in pounds per inch run

$P$ = pressure in pounds per square foot

$S$ = distance between the ribs, in feet

$e$ = the strain in the fibres due to the fabric hogging between the ribs under the pressure.

This relation is obtained upon the assumptions that the transverse fibres alone withstand the pressure, and that the radius of curvature of the fibres is large compared with $S$.

If there is an initial stress in the fabric, the above expression must be modified accordingly and takes the form of

$$t = \text{P. S.} \sqrt{\frac{1}{24\,(e - e_0)}}$$

where $e_0$ is the initial strain.

Values of $e$ are obtained from the load-stretch curves for the particular fabric.

The following values have been worked out from the above formula, for the case of a linen fabric, for S = 0·92 feet.

| *Tension in Fabric, t pounds per inch.* | | *Percentage Extension, e.* | | *Air Pressure, P. pounds per square foot.* | *Factor of Safety.* | |
|---|---|---|---|---|---|---|
| *Warp.* | *Weft.* | *Warp.* | *Weft.* | | *Warp.* | *Weft.* |
| 6 | 5 | 0·45 | 0·65 | 25 | 16 | 18 |
| 10 | 7·5 | 0·83 | 1·00 | 50 | 9·7 | 12 |
| 14 | 11·5 | 1·30 | 1·70 | 100 | 6·9 | 8 |

## Attachment of Aeroplane Fabrics.

Aeroplane fabrics are supplied in lengths up to 80 or 100 yards and in widths of from 34 to 50 inches. The fabric is usually cut and machine-sewn to the shape of the plane to be covered, both sides being allowed for.

The usual method is to arrange for the longer threads, or warp, to be parallel to the chord of the wing, the extreme width of covering being obtained by sewing several widths together, side by side.

Alternatively, planes are sometimes covered with the warp

and weft threads running diagonally at 45° to the chord; this arrangement gives greater flexibility along and across the chord, and is often employed for flexible and variable camber wings.

The wing ribs, which give the necessary shape, should be spaced at from 9 inches to 12 inches apart, and it is an advantage to cover the first few inches of the leading edge with special plywood of from $\frac{1}{8}$ inch to $\frac{3}{16}$ inch thickness in order to obtain a smoother surface.

When two pieces of fabric are joined, the edges should be doubled together, with an overlap of from $\frac{5}{8}$ inch to $\frac{7}{8}$ inch, and double sewn at each edge; it is an advantage to arrange the seams to come over the wing ribs so that they can be additionally secured.

The fabric is usually cut out and machined in one large sheet so that it is sufficient for both upper and lower surfaces; it is then held at the trailing edge of the wing and passed over the leading edge and back underneath to the trailing edge, where the two edges are double-sewn in place.

The fabric should be hand-stretched before sewing to suit the dope that is employed; it is sometimes lightly tacked in position before sewing. Another method consists in making a pocket of the covering and slipping it over the frame; it is then tacked and sewn in place.

The trailing edge of the wing may be either a wooden or tubular metal member, or a small steel wire of from 16 to 12 S.W.G.; in the latter case the wing trailing edge, when the fabric is doped, will become serrated in appearance.

There are several methods of fastening the fabric, of which the two most important are the method of sewing the fabric around the ribs, and the linen tape-and-tack method.

## Sewing Method of Attachment.

This is undoubtedly the strongest method of fastening the fabric to the ribs, and it consists in connecting the top and bottom sides of the fabric by a knotted sewing at intervals

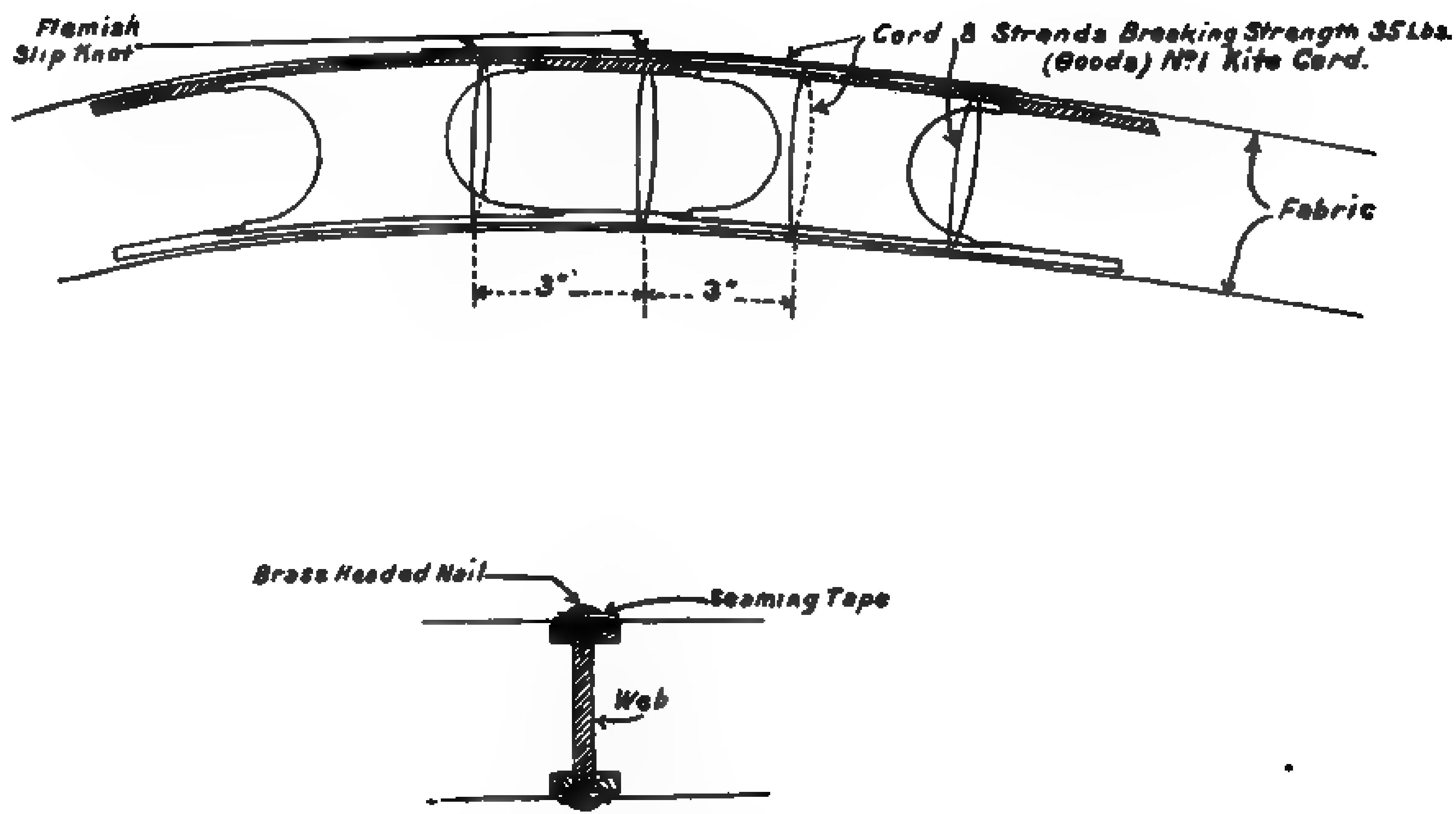



Fig. 106.
Showing R.A.E. Method of Fastening Fabric to Wing Surfaces, etc.

of about 3 inches, along each rib, the exposed part of the sewing being covered either with a line of tape glued or doped on and tacked, or, more advantageously, with frayed linen tape doped in place.

Tests* have shown that whereas the ordinary method of taping and tacking the fabric would just withstand a maximum loading of 100 pounds per square foot, the sewn fabric

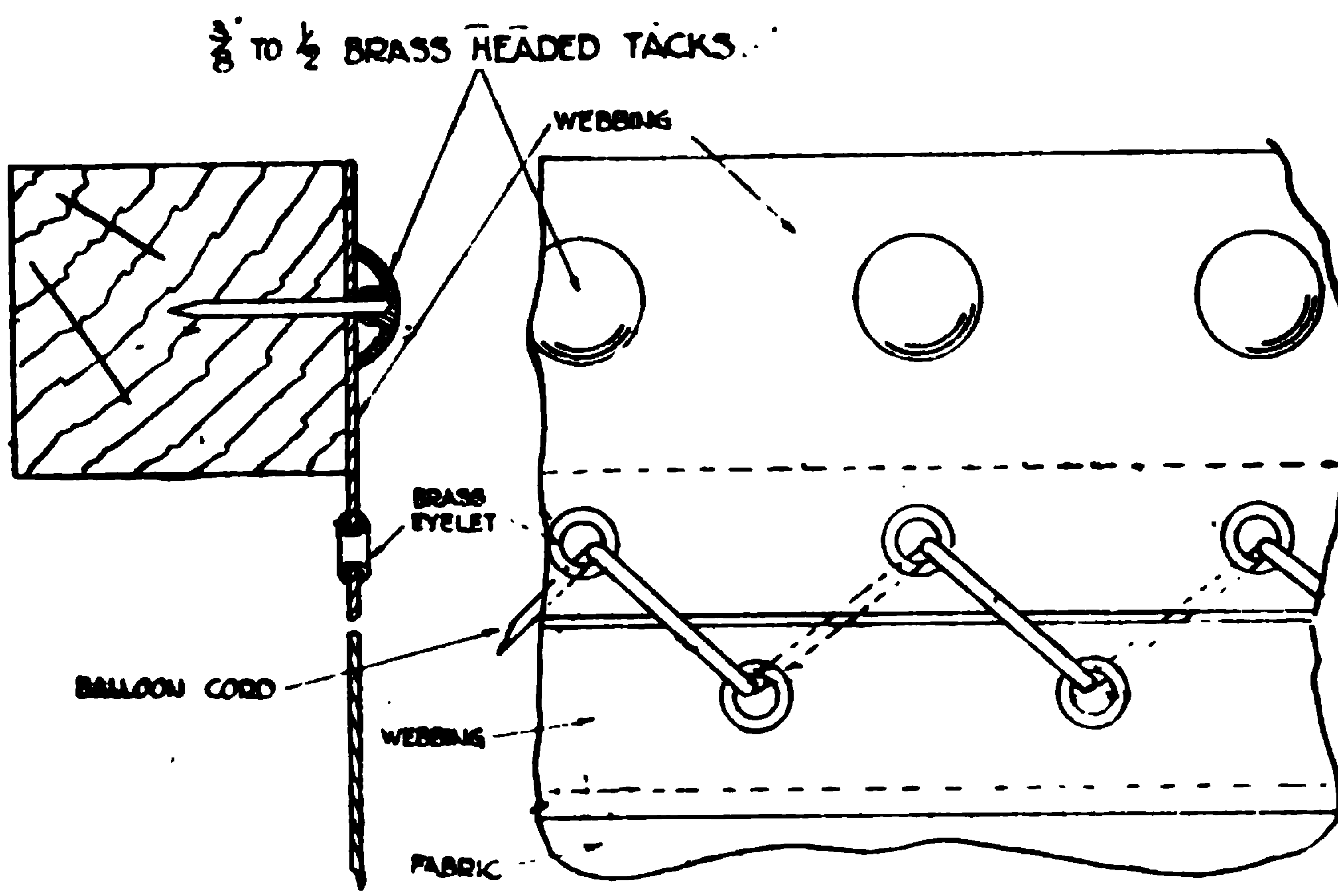



FIG. 107.—METHOD OF ATTACHMENT OF FABRIC ON FUSELAGES, ETC. (DETACHABLE.)

method withstood a maximum loading of 250 pounds per square foot, and at this intensity the ribs and spars were badly distorted and bent.

Fig. 106 shows the method of sewing the upper and lower surfaces of wing fabrics.

The following are brief working instructions for this method—

(1) After the fabric has been machined up to the required size, see that it is thoroughly dry.

(2) Lay the fabric round the plane, and first stitch tightly

* "Note on Wing Covering." Report No. 85., Jan, 1913. Advis. Com. for Aeronautics.

along the trailing edge. The final stretching should be done from both ends of the plane, to assure a good curve.

(3) The plane is now ready for sewing off with string. An upholsterer's needle and No. 1 kite cord should be used, and the pitch of the stitches should be 3 inches. The stitches are tied off at every stitch, as shown in (2) Fig. 106. The plane is now ready for receiving seaming tape.

(4) Dope down every rib, top and bottom, and the trailing edges, and lay on strips of frayed linen fabric about 1¼ to 1½ inches wide and dope in position.

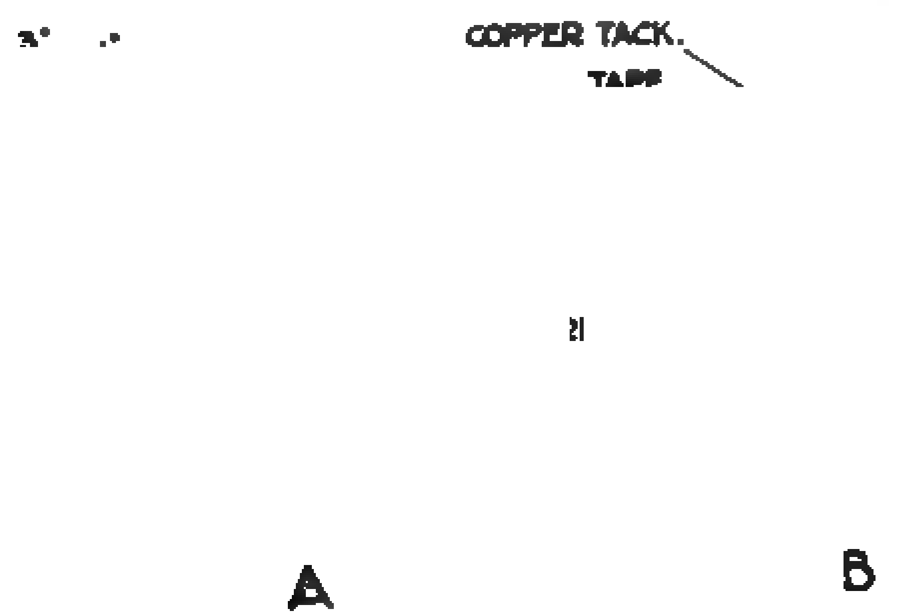



FIG. 108.—METHODS OF ATTACHING FABRIC TO RIBS, ETC. *A*, U.S. ARMY METHOD; *B*, ORDINARY METHOD.

(5) For tacking, when tape is used for covering the sewn threads, use brass-headed nails with ⅜ inch shanks, well roughened. Tack through the seaming tape and rib, as shown in (3) Fig. 107, taking care to avoid splitting the rib.

## Tacking Method of Attachment.

In this method, the fabric is tacked to the leading edge and the ribs with copper, or, better still, roughened brass nails, the fabric being given a preliminary doping, or gluing, or shellac-varnishing, so as to adhere to the ribs and other surfaces with which it is in contact.

The United States Army method was to use a thick brown

tape varying in width from $\frac{3}{4}$ inch to $1\frac{1}{4}$ inch, between the heads of the outer tacks and the fabric, dope being used as an adhesive. It has been shown that, by using roughened tacks, tape, and dope for sticking the fabric down, that the fabric covering will withstand a maximum pressure intensity of loading, tending to pull it away from the frame, of about 130 pounds per square foot, and a mean loading of 80 pounds per square foot. This method does not, however, enable the full bursting strength of the fabric to be developed.

## R.A.E. Specification for Linen Fabric.

1. Fabric.—The fabric is to be made from the finest Courtrai flax, closely woven and unbleached.
2. The yarns are to be wet spun with a moderate amount of twist, and to be regular in count and strength.
3. The cloth is to be free from slubs, snarls, knots, and other defects due to faulty preparation, spinning, weaving, or finishing.
4. All non-cellulose matter and loose dressing to be removed in boiling and no size or filling agent of any description is to be used in finishing.
5. The cloth must not be calendered.
6. Width.—The width is not to be less than 36 inches, and is not to vary more than $\frac{3}{8}$ inch above or below the stated width.
7. Weight.—The weight is not to exceed 4 ounces per square yard.
8. Ends.—Ends per inch = 96.
9. Picks.—Picks per inch = 100 (not to vary more than 3 picks above or below 100).
10. Strength.—The minimum strength of the fabric must be—

    Warp, 91 pounds per inch width.
    Weft, 102 ,, ,, ,,

11. The fabric will be tested for strength on an "Avery" testing machine. The rate of loading employed during tests will be 150 pounds per inch width per minute. Specimens will be 8 centimetres wide and 15 centimetres between jaws of the machine. These specimens will be soaked in water for 2 hours, and the excess of adherent water removed before placing them in the jaws of the machine.

## R.A.E. Specification for Linen Fabric with Missed Warp Threads for Cutting into Strips.

1. Fabric.—The fabric is to be made from the finest Courtrai flax, plain woven and unbleached.
2. It is to be woven in strips of $1\frac{1}{4}$ inches each, by leaving out of the reed a $\frac{1}{2}$ inch of warp every $1\frac{3}{4}$ inches.
3. There should be a selvedge of $\frac{1}{2}$ inch at each side to be followed by $\frac{1}{2}$ inch of missed warp.
4. The yarns are to be wet spun with a moderate amount of twist, and to be regular in count and thickness.
5. The cloth must be free from slubs, snarls, knots, and other defects due to faulty preparation, spinning, weaving, or finishing.

6. All non-cellulose matter used in preparation of the warp to be removed by boiling, and no size or filling agent to be used in finishing

7. The cloth must not be calendered.

8. WIDTH.—The width is to be $37\frac{1}{2}$ inches and should not vary more than $\frac{3}{8}$ inch above or below width stated by manufacturer.

9. WEIGHT.—The weight is not to exceed $3\frac{3}{4}$ ounces per square yard.

10. ENDS.—Ends per inch, 92 to 96.

11. PICKS.—Picks per inch, 100. (Not to vary 3 picks above or below 100.)

12. STRENGTH.—The minimum strength of the fabric must b›—

Warp, 91 pounds per inch
Weft, 102 „ „

13. Strength tests will be made on a constant rate of loading machine. Tests will be made on specimens $1\frac{3}{4}$ inches wide × $8\frac{1}{2}$ inches between the jaws of the machine. The rate of loading employed during these tests will be 150 pounds per inch width per minute. The specimens will be soaked in water for 2 hours, and the excess of adherent water removed before placing them in the jaws of the machine.

## BALLOON AND AIRSHIP FABRICS

These fabrics differ from those used for aeroplanes in that they must be very impermeable to hydrogen or air, and must be moisture and weather-proof. They should be as light as possible in weight.

The lowest leakage for a rubber-proofed fabric is about 5 litres per square metre per 24 hours, for a parallel doubled proofed silk about 1 to 2 litres, and for several layers of goldbeaters' skin the leakage is almost negligible.

Cotton is probably the most widely used fabric for kite and other balloons, in spite of its being weaker than linen fabric.

Silk has been used to some extent on the Continent, but it is considered to be dangerous, owing to its electrostatic properties; moreover, its cost is very high. Silk does not vulcanize at all well, so that it is not used for rubbered fabrics.

Linen has been used in cases where exceptional strength was required, but rubbered linen fabrics in general weigh more than the cotton fabrics.

Rubber is widely used as a proofing material on account of its impermeability to hydrogen, adhesion, ease of working

and making joints, and its flexibility; it is possible to employ several layers of fabric, to increase the strength and gas-tightness. Rubbered fabrics require protecting* against the effects of the ultra-violet rays of sunlight and weathering in general.

Oiled fabrics have been used, but they are sensitive to thermal changes and need handling with care.

Probably one of the most gas-tight and the strongest of fabrics for airships is the rubber-proofed single or double ply cotton fabric, to the inside of which is cemented or solutioned one or more layers of goldbeaters' skins, the outside being pigmented or otherwise protected against weathering effects.

The cotton fabric employed in the manufacture of rubbered airship and balloon fabrics has, approximately, the following strengths—

TABLE CXXI.

STRENGTH OF COTTON FABRICS.

| *Weight in ounces per square yard.* | *Strength in warp and weft, pounds per inch.* |
|---|---|
| 2 | 30 |
| 2½ | 42 |
| 3 | 53 |
| 3½ | 65 |
| 3¾ | 74 |

The properties of some balloon fabrics tested by the N.P.L. Authorities are given in Table CXXII.

## Rubbered Fabrics.

The rubbered fabrics employed for balloon and airship work are of two and three-ply cotton types.

The two-ply fabrics consist of two layers of cotton fabrics, with either a plain, colour-pigmented, aluminium, or rubber

* See. p 332.

coated outer face (exposed surface), a layer of rubber between the plies, forming from 20 to 70 per cent. of the thickness, and a plain or rubber-coated inner face, exposed to the contained gas.

## TABLE CXXII.

### Properties of Aircraft Coverings.

| *Material.* | *Weight in grammes per sq. metre.* | *Tensile strength, kilogrammes per metre width.* | | *Permeability in litres per sq. metre per 24 hrs.* |
|---|---|---|---|---|
| | | *Warp.* | *Weft.* | |
| (*a*) Rubbered Fabrics. | | | | |
| Single Rubbered Fabric .. | 226·5 | 742 | 768 | 12·5–12·8 |
| Double Fabric, 1 layer rubber | 271 | 1500 | 1089 | 13–13·9 |
| Parallel Doubled, 2 layers rubber, uncovered .. | 241 | 948 | 923 | 6·4–11·4 |
| Parallel Doubled, 3 layers rubber, uncovered .. | 330 | 1539 | — | 17–18 |
| Diagonally Doubled, 2 layers rubber, yellow .. .. | 325 | 1037 | 1120 | 7–8 |
| Diagonally Doubled, three layers, rubber, yellow .. | 328 | 679 | 571 | 2·3–6·7 |
| Trebled Fabric .. .. | 316 | 2304 | 2197 | 11–15 |
| Oilskin .. .. .. | 247 | 1195 | 1630 | 0·5 |
| Double Silk, varnished .. | 191 | 1055 | 1054 | 2·7–3·3 |
| Cotton, proofed .. .. | 284 | — | — | 11·6–15 |
| Single Silk, unproofed .. | — | 660–893 | 660–893 | — |
| Goldbeaters' Skin, 4 layers | 91 | — | — | 0·28 |
| ,, ,, 5 ,, | 111 | — | — | 0·42 |
| ,, ,, 8 ,, (strapped) .. .. | 301 | — | — | 0·10 |
| Goldbeaters' Skin .. .. | — | 779 | — | — |

The three-ply fabrics are similar to the above, but they possess three cotton fabric layers with rubber in between; the outer or exposed layer is protected in the same manner against ultra-violet light and weathering effects.

In all cases the rubber is vulcanized to the fabrics. The plies may be either biassed or parallel.

Table CXXIII gives the properties of some typical rubbered fabrics used for balloons and airships.

## TABLE CXXIII.

### PROPERTIES OF RUBBERED FABRICS FOR BALLOONS AND AIRSHIPS.

| *Material.* | *Weight in grams per sq. metre.* | *Permeability in litres per sq. metre per 24 hrs.* | *Tensile Strength killogrammes per metre.* | | *Remarks.* |
|---|---|---|---|---|---|
| | | | *Warp.* | *Weft.* | |
| Parallel, rubbered cotton, outer layer red .. .. | 270 | 6 | 1685 | 1685 | For spherical balloons and small dirigibles |
| Fine cotton fabric, biassed outer layer yellow .. | 247 | 10 | 1685 | 1685 | Light fabric for balloons |
| Fine light cotton fabric, parallel, inside rubber proofed .. .. .. | 187 | 10 | 980 | 1100 | Light fabric for balloonets of non-rigid and gas envelopes of rigid airships |
| Two ply cotton, biassed, inside ply proofed (rubber), outside ply dyed deep yellow .. .. | 240 | 10 | 1685 | 1685 | Suspension patches gas valves, balloons and light airships |
| Two ply cotton, parallel, outer ply dyed deep yellow, inner ply proofed (rubber) .. .. | 350 | 7½ | 2650 | 2650 | Suitable for larger non-rigid airships and patches, kite balloons |
| Two ply linen, parallel, back ply proofed, outside ply dyed yellow and protected with layer of litharge proofing and aluminium. (North British Rubber Co.) .. | 420 | 10 | 3450 | 3450 | For large dirigible |
| Single ply cotton fabric. proofed (rubber) inside, dyed yellow outside .. | 187 | 10 | 840 | 795 | For small spherical balloons and balloonets |
| Proofed single silk, aluminium painted .. | 281 | 1·1 | 874 | 874 | For balloons |
| Single ply cotton, proofed one side rubber, lined 1 layer goldbeaters' skin, inside varnished .. | 165 | 0·5–1·0 | 890 | 890 | For gas-bags of large rigid airships |
| Three ply cotton, centre ply on bias, rubber layers between, plain outside | Rubber 150<br>Fabric 315<br>Total 465 | 5–10 | 2500–3000 | 2500–3000 | For large non-rigids, ripping panels, and ballast bags |
| Two ply cotton, parallel, inner rubber layer, aluminium faced .. .. | Cotton 150<br>Rubber 120<br>Alum. 30<br>Total 300 | 5–8 | 2000–2500 | 2000–2500 | Envelopes of non-rigids |

## Airship Fabrics.*

The material used for the envelopes of non-rigid dirigibles is usually a two-ply fabric with rubber between the layers, rubber inside, and either a red or yellow pigment outside;

* Also see p. 387 *Aeron. Journal*, July, 1919, "Fabrics for Airships Lighter-than-Air Craft." T. R. Cave-Brown-Cave.

yellow dyed, or aluminium coated outer layers. One or two typical examples are given in Table CXXIII.

For the inner balloonets a single-ply fabric rubbered on both sides, or coated on the inside with goldbeaters' skins varnished, and rubbered outside, is used.

For large non-rigid dirigibles, heavier two-ply or three-ply rubbered fabrics are used.

For kite balloons a two-ply rubbered fabric, dyed yellow outside and rubbered with from 20 to 30 grams per square metre inside, is employed for the envelopes and balloonets.

The gas bags of rigid airships are usually made with the single or double skin-coated rubbered single or two-ply fabrics outlined in Table CXXIII; the weight varying from 160 to 200 grams per square metre; such fabrics are very gas-tight, durable, and strong. Varnishing the skins improves their gas-tight and durable qualities.

For gas valves, girdles, suspension patches, filling sleeves, and similar purposes, it is usual to employ a two or three-ply rubbered fabric, according to the load coming upon the material.

The outer envelopes and fin covers of rigid airships are usually made of a good grade of single-ply linen, doped and varnished. It is usual to employ a stronger grade (160 to 190 grams per square metre) for the bow portion, where the air pressure is greater, and a light grade (100 to 130 grams per square metre) for the fin-coverings.

### Sizes of Fabrics.

The widths of balloon fabrics vary from 36 to 50 inches, the average being 36 to 40 inches, and the lengths up to 50, 80, or 100 yards.

### Kite Cords.

Kite cords are used for fastening fabric coverings to wing framework, for lacing fuselages, and for balloon and airship

work. They are generally spun from flax fibres. The following are the properties of aeronautical kite cords—

## TABLE CXXIV.

### Properties of Aircraft Kite Cords.

| *Designation.* | *Constitution.* | *Maximum weight per 100 yards in ounces.* | *Minimum permissible strength in pounds.* |
|---|---|---|---|
| No. 1 Kite cord | 8 flax threads twisted together .. .. | 3 | 33 |
| „ 3 „ „ | 3 strands of No. 1 .. | 10·5 | 100 |
| „ 6 „ „ | 6 „ „ .. | 21 | 200 |
| „ 9 „ „ | 9 „ „ .. | 32·5 | 300 |
| „ 12 „ „ | 12 „ „ .. | 48·0 | 400 |
| „ 15 „ „ | 15 „ „ .. | 60·0 | 500 |

### R.A.E. Specification for Cordage.

Cordage.—All cordage is to be of the finest Italian hemp and supplied in hanks of 60 yards.

Weight.—The weight of the hank is not to vary more than 5 per cent. above or below the weight stated hereunder.

All cordage is to comply with the following test—

Strength.—

| *Size of cord.* | *Strength.* |
|---|---|
| 2 pounds hank | 400 pounds |
| 1½ „ „ | 310 „ |
| 1¼ „ „ | 265 „ |
| 1 „ „ | 220 „ |
| ¾ „ „ | 175 „ |
| ½ „ „ | 130 „ |
| ¼ „ „ | 75 „ |
| ⅛ „ „ | 45 „ |

The above strength values are minima. All cordage is to be inspected and tested for strength. The tests will be carried out on an "Avery" testing machine, and the rate of loading during test to be 600 pounds per minute. Test pieces will be 60 centimetres long.

## CHAPTER VIII

# DOPES AND VARNISHES

## DOPES

THE fabric used for covering aircraft surfaces, such as the wings, control surfaces, fins, and fuselages, is usually stretched over the structure, which is designed to give the correct shape, and tacked into position.

It is not sufficient to leave the stretched fabric in this state, as it is very susceptible to humidity changes and would slacken or tauten with every increase or decrease of atmospheric moisture, and would also " age " fairly quickly.

In order to permanently protect the fabric against the effects of the weather, moisture, and other influences, it is painted with a solution known as " dope," the functions of which are—

(*a*) To render the fabric weather-proof, and prevent " ageing."

(*b*) To tighten the fabric to the right degree.

(*c*) To render the fabric oil, petrol, and water-proof.

(*d*) To give a smooth surface for varnishing.

A good dope should dry fairly quickly, that is to say, in a few hours, and should not crack or curl under weather influences ; it should be light in weight, transparent when " set," and non-poisonous. It should also preferably be fire-proof.

### Constitution of Dopes.

Most modern dopes are solutions of a cellulose base, or film-forming material, in a suitable solvent, with the additions of certain substances to render the resulting film flexible, water, oil, weather-proof, and fire-proof.

There are two types of cellulose dopes in wide use, namely, those with a *cellulose nitrate* (or pyroxylin) base, and those

with a *cellulose acetate* base, of which the latter are the more widely employed.

Cellulose nitrate dopes are not in themselves fire-proof, and are considered to give a smaller tightening effect than the acetate dopes ; it is much cheaper than the latter dope, however.

The solvents commonly employed for cellulose acetate are acetone and tetrachlorethane ; the latter solvent is not now used to any extent on account of its poisonous properties. The vapour of this latter solvent is heavier than air, and sinks to the ground ; for this reason, dope rooms are usually provided with gratings or air-ventilators at ground level to disperse the fumes.

When the solvent of the cellulose acetate evaporates, it leaves a film which shrinks and hardens as the last traces of the solvent pass away, and in shrinking, tightens the fabric.

Such films are, in themselves, too brittle to last long under practical conditions, and therefore require "softening" or "plasticising" agents ; they also require the addition of substances to render them water and fire-proof (if not already so). A typical plasticising agent is *benzyl alcohol*, and a suitable water-proofing substance is *triphenyl phosphate*.

The following is the formula* of a typical dope of the acetate class—

| | | |
|---|---|---|
| Cellulose acetate .. .. | 7·5 | per cent. by weight |
| Triphenyl phosphate .. | 1·0 | ,, ,, |
| Benzyl alcohol .. .. | 3·0 | ,, ,, |
| Acetone .. .. .. | 88·5 | ,, ,, |

The acetone is a solvent for the other three substances.

The specifications for cellulose acetate and nitrate dopes, as recommended by the Society of Automotive Engineers, are given at the end of this section.

In connexion with these two dopes, it may be mentioned that the results of tests* tend to show that, in general, cellulose acetate dopes are superior to the nitrate dopes for use on

* "The Less Satisfactory Materials of Aircraft Construction." G. S. Walpole, *Aeron. Journ.*, Jan.-Dec., 1917.

cotton; the decrease in tensile strength on exposure to the weather is much less with the acetate than with the nitrate dopes. The same is true, but to a lesser extent, in the case of linen fabrics.

**Pigmented Dopes and Pigments.**

It is now established that the real cause of the deterioration in strength of doped fabrics, under ordinary flying conditions, is due to the action of the ultra-violet rays of sunlight; the effect of the other agent, such as heat, moisture, bacteria, moulds, etc., being inappreciable in comparison.

It is known that the painted doped fabric of old machines, for example, at the identification marks, is very much stronger than the unpainted doped and varnished fabric on other parts of the same machine, the difference being most marked in cases where tetrachlorethane dopes had been used; it is believed that the effect of sunlight was to liberate chlorine and hydrochloric acid, which attacked and weakened the fabric.

For these reasons, this class of dope was abandoned and a protective pigment was embodied in the composition of the dope itself, to nullify the action of the sunlight. There are about 150 dyes soluble in cellulose acetate dope, of which about half-a-dozen give satisfactory results.

The type of dope known as "Raftite" showed only 15 per cent. decrease in strength for the fabric after 12 months exposure, when about 1 per cent. of a suitable dye was included in its composition*; moreover, the qualities of the dope, as regards tautness, were considerably improved by pigmentation.

A protective pigment varnish which has been successfully used for painting doped fabric is that known as "P.C. 10,"† a dark khaki-coloured varnish which not only protects the

* "Aeroplane Fabric: Problems of Preservation." W. F. Aston, *Aeron. Journ.*, Feb., 1919.

† "Raftite" and "P.C. 10" were both produced, in the first place, at the Royal Aircraft Establishment.

dope layer from light and moisture, but prevents volatilization of the plastic agent; the weight of the layer is very small.

Pigments used for protection, either in varnish or dope, must have a high extinction coefficient for actinic light, must be capable of being ground extremely fine (since a given weight of pigment will cover an area directly proportional to its fineness), and must be chemically inactive to any of the dope constituents.

The *natural oxide of iron* known as *ochre* possesses all of these properties, and is also very cheap; when mixed with the correct proportion of *lamp-black* it gives a khaki shade, and is a valuable pigment for dopes or varnishes of the P.C. 10 type.

For tropical work, finely powdered aluminium is especially suitable for protection purposes, in the same manner as for balloon fabrics.

Dyes have been used for camouflaging aeroplanes; in some cases the dyes were printed on by machinery in polygonal patterns before the fabric was placed on the machine. Most of these dyes, however, fade rapidly under ordinary flying conditions.

It is estimated that a pigmented varnish of the P.C. 10 type, when properly applied, adds about 1 ounce per square yard to the weight of the fabric, exclusive, of course, of the dope weight.

## Tautness and Number of Coats.

The degree of tautness in the fabric covering of aircraft structures is a very important factor in the life of the fabric and its efficiency; if too tight, it tends to distort and buckle the structure, and if too loose, it is "soggy," that is, it constantly flaps or vibrates and detracts from the machine's performance.

There are two principal methods adopted for obtaining the correct degree of tautness, namely—

(*a*) To stretch the fabric on the framework as tightly as possible and apply a dope of slight shrinkage power.

(*b*) To stretch the fabric less tightly and use a dope of high shrinking power.

There appear to be advantages in both methods.*

Tautness is the greater, the more rapid the evaporation of the solvent; methyl acetate, methyl formate, and acetone in abundance in the solvent all lead to tautness; this is lessened by the plasticising agent added; for example, "Raftite" gives a much tauter result if the benzyl alcohol is left out.

The tautness increases with the number of coats up to a certain point, and then each successive coat makes less and less difference; the number of coats employed in practice varies from 4 to 6, of which the first and second have the greatest tautening effects, and the last coat the least.

For the same fabric the tautness will depend upon the composition and number of coats of the dope used; the following table will serve to illustrate the latter point—

TABLE CXXV.

EFFECT OF NUMBER OF COATS OF DOPE UPON TAUTNESS.

| *Number of coats.* | *Load in grammes.* | *Tautometer Readings.* | |
|---|---|---|---|
| | | *High viscosity acetate dope.* | *Low viscosity acetate dope.* |
| 0 | 200 | 50 | 49 |
| 2 | 200 | 30 | 30 |
| 3 | 200 | 21 | 20·5 |
| 4 | 200 | 18 | 18 |
| 4 | 500 | 32 | 32 |
| 5 | 500 | 24 | 24 |

Apart from the nature of the dope, the tautness will depend upon the structure, and type of the fabric. The ability of a

* It is stated by Dr. Aston (see Footnote on p. 372) that if the fabric is originally very tightly stretched, the first coat of dope will let it down, but after five coats of dope have been applied, the result is the same, whether the fabric in the first place is slack or not; that is, the final tautening effect is independent of the initial tautness.

fabric to "take the dope" is influenced almost entirely by the relations between the yarn number, twist, threads per inch, weight, and weave; other things being equal, the degree of twist of the thread plays an important part, there being a certain limiting degree of twist.

In order that the dope film shall not be too heavy, the yarn should have as little hysteresis effect as possible; this effect is only fully attained at the expense of over-twisting and consequent loss of tensile strength.

The greatest tautening effect of dope occurs upon the fabrics of fine texture; fabrics of lower count and greater weight than the standard are slacker when doped.

Dopes owe their tightening properties to the fact that they are colloids, and therefore do not penetrate the material of the fibre but merely fill the interstices of the yarns, and one side for the fabric coated; as the solvent evaporates the globules contract in both directions in the plane of the fabric, and also in thickness, and thus produce the tightening effect. The first two coats (each of which should be carefully and evenly applied in an atmosphere of the correct temperature, and should be allowed to dry) fill up the interstices between the threads and give the greatest tightening effect, whilst the last two, three, or four coats act as fillers, or smoothing coats; the ultimate effect is a smooth, flat surface.

Sometimes two or three coats of dope are applied, followed by a coat of a mixture consisting of two parts dope to one of spar, or linseed varnish, and finally one of varnish alone.

Fig. 109 shows a magnified view of a section of linen which has been doped rather liberally, and finally coated with a layer of P.C. 10 pigment varnish.

### Protection of Underside of Fabrics.

It will be observed from Fig. 109 that there is little if any dope upon the under surface; it is on this surface that the effects of moisture and bacteria are liable to be felt, and the method of lightly doping, rubbering, or otherwise protecting

this surface is recommended for machines which are required for long service.

The presence of air bubbles and of any of the lubricants used for weaving on the warp threads, such as tallow, leads to unsatisfactory coatings.

FIG. 109.—MICRO-PHOTOGRAPH OF DOPED LINEN FABRIC.

### Tautometers.*

The function of most tautometers used in connexion with dopes and fabrics is to afford an absolute, or comparative, measure of the tightness (or "tautness") of the fabric or covering. The principle upon which many of these instruments work is that of indicating, usually through a magnifying system of levers, the amount of deflection produced by a known weight upon a surface of known shape and area.†

* Also see "Fabric and Dope," by F. W. Aston. *Aeron. Journal*, May, 1919.

† The Engineering Standards Committee give the following definition (1918) for tautness: The tautness $T$ of a doped surface shall be defined by the expression $T = \frac{RP}{2}$ where $R$ is the radius of curvature, and when a difference of pressure $P$ is maintained between the sides of the doped surface, that the difference of pressure should be as nearly as possible 1 inch of water (2490 dynes/cm.$^2$) and that the value of the tautness should be expressed in pounds per inch or kilogrammes per metre.

The standard R.A.E. frames measure 12 inches square, and the fabric is stretched at constant tension (2 pounds per inch warp, 1 pound per inch weft).

Fig. 110 illustrates the results* of some tautometer tests upon slack and taut fabric, which have each been given five successive coats of dope. The curves marked $S$, $S_{I}$, $S_{II}$, etc., denote the tautometer readings for the slack fabric in the original condition, and with one, two, etc., coats of dope. The curves marked $T$, $T_{I}$, $T_{II}$, etc., refer to the taut fabric. It will be observed that the ultimate tautness $S_{v}$ and $T_{v}$ are nearly the same.

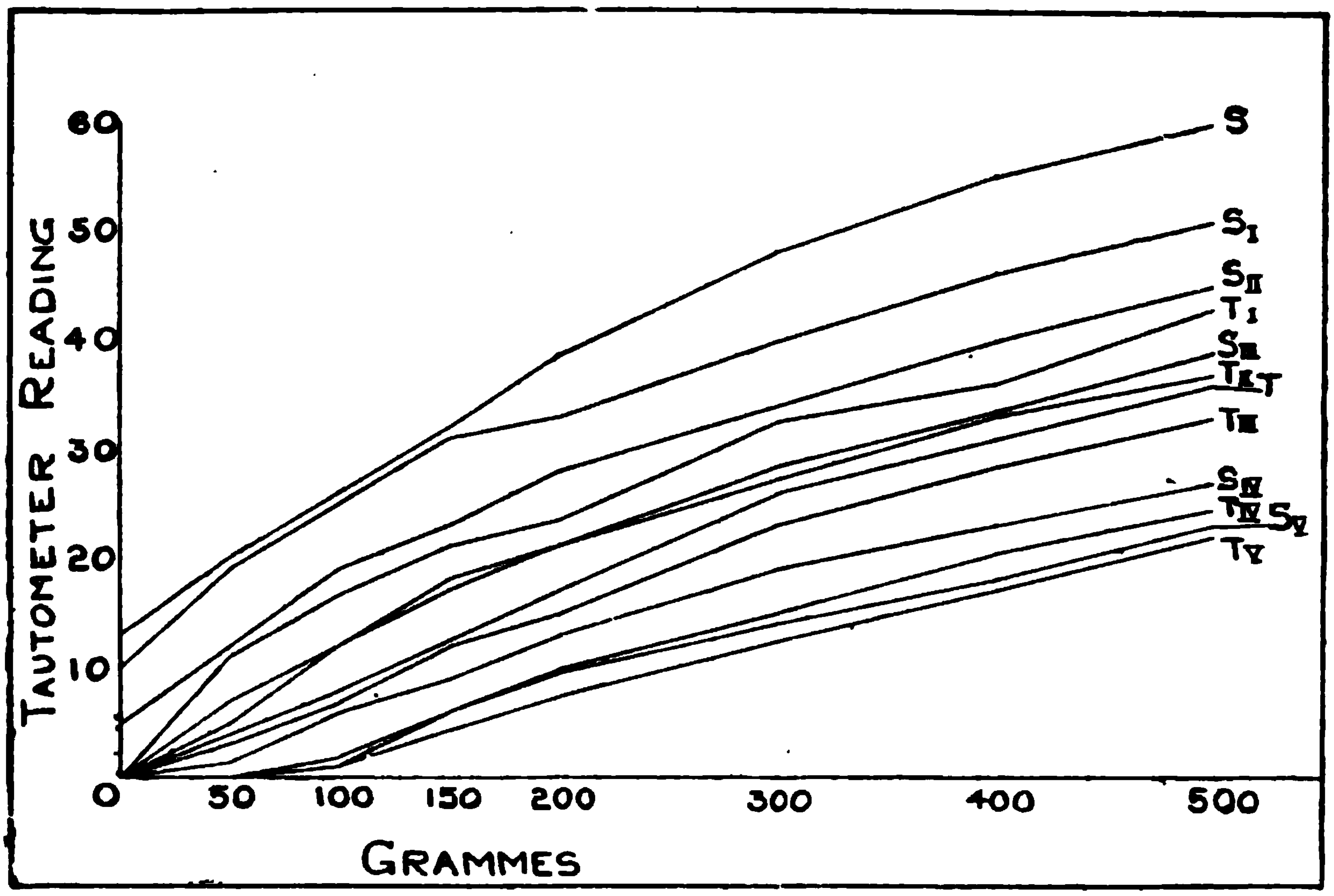



FIG. 110.—EFFECT OF NUMBER OF COATS OF DOPE UPON TAUTNESS.

Fig. 111 illustrates a typical tautometer device, in outline. It consists of an ordinary balance arm $A\ B\ C$, pivoted at $B$, the vertical position of the pivot being adjustable by means of the milled screw $M$. The ratio of the arms $BC$ and $AB$ is usually about 5 or 10 to 1, and the small rider weight $w$ should be from $\frac{1}{5}$ to $\frac{1}{10}$ the weight $W$.

The tautometer is first adjusted so that when the beam lever index $C$ is opposite the zero on the scale, the weight ball $W$ is just touching, but not deflecting the fabric $FF^{1}$.

* Dr. Aston, The *Aeron. Journ.*, Jan.-Mar., 1917.

To obtain a reading, the smaller weight $w$ is either taken off bodily or moved along the beam $BC$ towards the fulcrum $B$.

The deflection at $d$ of the fabric due to the known weight increase at $d$ when $w$ is removed or slid along, is shown multiplied upon the scale $s$.

The size of the frame, which should be kept the same for comparative tests, is usually from 12 to 24 inches square, and the weights used for ascertaining the deflections vary from 0 to 500 grammes.

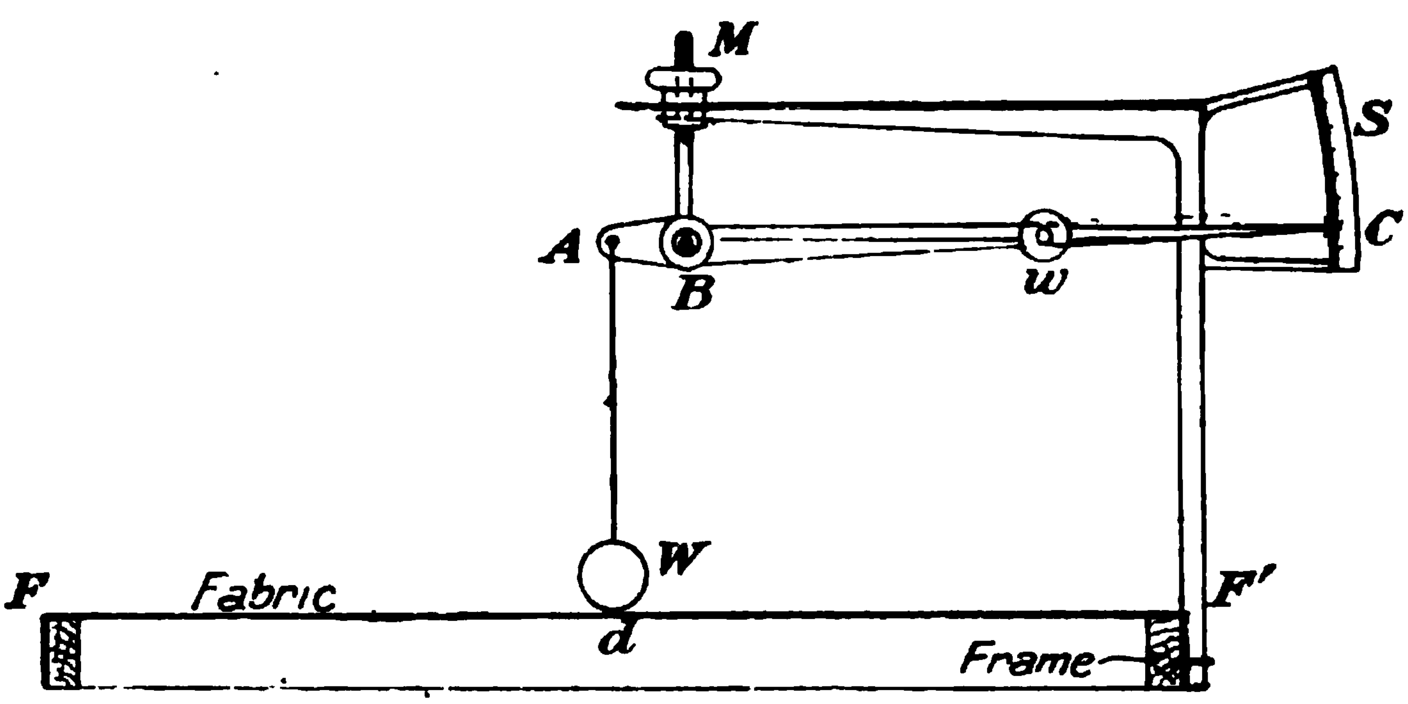



FIG. 111.—ILLUSTRATING PRINCIPLE OF TAUTOMETER.

## Effect of Dope on Properties of Fabrics.

The weight of the dope and varnish film (five coats in all) for ordinary linen and cotton fabrics varies from 2 to 4 ounces per square yard ; it is usual to specify the latter figure as a maximum value. The tensile strength of linen fabric is increased by from 20 to 30 per cent. by doping, and of cotton fabric by from 15 to 20 per cent.

The effect of properly doped fabric is to appreciably increase the breaking strength of aircraft structures, such as wings, control areas, and fuselages, the increase in strength in the case of a small two-seater amounting to from 10 to 20 per cent.

### Amount of Dope Required.

The area covered by a given quantity of dope depends upon several factors, amongst which may be mentioned the composition and viscosity of the dope, the nature of the fabric, and the temperature of the dope-room.

The total quantity of dope required to cover a small two-seater tractor aeroplane of about 350 square feet wing area, and including the fabric sides of the fuselage and tail control and stabilizing planes varies from 7 to 10 gallons.

An average value for the covering power of a good dope is from 6½ to 10 square yards per gallon, applied in from four to six coats.

### International Aircraft Standard Dopes.

The International Aircraft Standards Board Committee have issued specifications for standard acetate and nitrate dopes.

INTERNATIONAL AIRCRAFT STANDARD DOPES.

The Committee recommend that two coats of acetate dope be substituted for spar varnish on training machines. The temperature of the doping rooms of aeroplane factories should be maintained at 70° F., and the aeroplane manufacturers should store the dope under cover. The following specifications were proposed by the Committee—

CELLULOSE ACETATE DOPES.

*Definition.*—Dopes for aeroplane fabrics must consist of a clear uniform mixture of ingredients and be capable of shrinking the fabric to the degree of tautness desired by the Signal Corps inspection. The residual film should be reasonably transparent and free from white spots, and should give a smooth, homogeneous surface when applied in a horizontal position in an atmosphere not exceeding 65 per cent. humidity and 75° F. temperature and free from direct draught.

*Viscosity.*—The viscosity of the dope must permit direct application without dilution at a temperature not lower than 60° F.

*Coating.*—The dope, when dry, must adhere to the fabric with sufficient tenacity to prevent peeling off in sheets. Test strips should show lint attached to the side which has been in contact with the fabric.

*Effect on Tensile Strength and Weight.*—Four coats, or an equivalent, of dope must, 48 hours after application, increase the tensile strength of linen fabrics not less than 25 per cent. of the original strength, and of cotton fabrics not less than 15 per cent. The increase in weight per square yard of doped fabric should not be less than 2 ounces nor greater than 3·5 ounces. The test shall be made under standard conditions of humidity and temperature, on standard fabrics.

*Acidity.*—No mineral acids may be present in the dope, and the amount of free organic acidity figured as acetic acid may not exceed 0·2 per cent. No compounds may be present which would be injurious to the fabric.

*Sulphates.*—Dopes which show the presence of free sulphuric acid by the test given below are not acceptable.

*Tetrachlorethane.*— Dopes containing tetrachlorethane are not acceptable.

*Cellulose Acetate.*—The cellulose acetate used should contain no free mineral acid, and not more than 0·1 per cent. of free acetic acid, and should be stable. The amount of cellulose acetate shall not be less than 60 grains per litre of dope.

*Solvents.*—The volatile solvents employed should present no danger to the workmen applying them.

*Inflammability.*—Five drops of petrol dropped on the film which has been dried for 48 hours, and immediately ignited, should have no more serious effect than to clear the fabric under the moistened section of the film.

*Exposure Test.*—Dopes must comply with the following test: A square 12-inch frame, inside measurement, is covered on both sides with fabric, the fabric being tacked to the outer side of the frame under uniform tension, simulating the conditions employed in aeroplane manufacture. Four coats, or an equivalent, of dope are to be applied to each side of the frame, each coat being allowed to dry thoroughly before the succeeding coat is applied. The frames are to be exposed on a roof in an unshaded horizontal position, one side being constantly uppermost. After 60 days of constant exposure no spontaneous cracking of the doped surface should be apparent, and after remaining 1 hour at a temperature of 70° to 80° F., the film shall not crack and shall have a decided ring. This test shall be made comparatively with a dope that has previously passed the test, and shall be in effect until a mechanical test is adopted.

*Shipment.*—Dope shall be shipped in metal cans, metal or wooden barrels, or earthenware containers. Inspection of the containers shall be permitted to insure against the accidental introduction of foreign material. The container shall be marked with the date of manufacture, serial number, gross, tare, and net weight.

TESTING OF DOPE.

*Acidity.*—A 500 c.c. beaker, containing about 200 c.c. of water, is counterbalanced on a large balance, which is adjusted to 0·01 gramme by adding or removing water. About 10 grammes of dope are poured into the water and the increase in weight noted. This is rapidly done to 0·01 gramme to diminish the solvent loss. The dope is stirred up and allowed to stand 10 to 15 minutes with occasional stirring. The liquid is decanted through a rather porous filter into an 800 c.c. beaker, and 150 c.c. of warm water added to the residue. It is allowed to stand 10 to 15 minutes with frequent stirring and poured through the filter into the 800 c.c. beaker. The residue is washed with 150 c.c. of warm water as before. A few drops of phenolphthalein are added and the solution titrated with tenth normal caustic soda to a colour that persists for ½ minute.

Some dopes, notably those containing much acetone, when poured into water precipitate as a milky solution containing shreds of the acetate. The resulting liquor filters slowly and passes through the filter paper in a cloudy condition. Since the acetate is finely divided, it is practically free from acetic acid, and additional washing is unnecessary. The end point is not quite as sharp as when all the acetate has been removed, owing to hydrolysis of the suspended material, but is sufficiently accurate for all practical purposes. Absence of mineral acids must be proved by qualitative tests.

*Sulphates.*—Twenty grammes of cellulose acetate drops are treated

with 150 c.c. of water in a pressure bottle at 100° for 24 hours. The resulting liquor is filtered and tested for free sulphuric acid.

*Amount of Cellulose Acetate.*—Pour 25 grammes of the dope into a Petri dish 6 inches in diameter, and evaporate to dryness on a steam bath. Extract the residue with ether in a soxhlet until all extractive material has been removed. Dry at 60° to constant weight, and weigh.

*Film.*—Pour some of the dope on a glass plate and allow to dry spontaneously. The film may be examined for the general characteristics of transparency, coherence, strength, and flexibility.

CELLULOSE NITRATE DOPES.

*Definition.*—Dopes for aeroplane fabrics must consist of a clear, uniform mixture of ingredients and be capable of shrinking the fabric to the degree of tautness desired by the Signal Corps inspection. The residual film should be reasonably transparent and free from white spots, and should give a smooth homogeneous surface when applied in a horizontal position in an atmosphere not exceeding 65 per cent. of humidity and 75° F. temperature free from direct draught.

*Viscosity.*—The viscosity of the dope must permit of direct application without dilution at a temperature not lower than 60° F.

*Coating.*—The dope, when dry, must adhere to the fabric with sufficient tenacity to prevent peeling off in sheets. Test strips should show lint attached to the side which has been in contact with the fabric.

*Effect on Tensile Strength and Weight.*—Four coats or an equivalent of dope must, 48 hours after application, increase the tensile strength of linen fabrics not less than 25 per cent. of the original strength, and of cotton fabrics not less than 15 per cent. The increase in weight per square yard of doped fabric should not be less than 2 ounces and not greater than 3·5 ounces. The test shall be made under standard conditions of humidity and temperature on standard fabrics.

*Acidity.*—No mineral acids may be present in the dope, and the amount of free organic acidity figured as acetic acid may not exceed 0·2 per cent. No compounds may be present which would be injurious to the fabric.

*Cellulose Nitrate.*—The cellulose nitrate used in the manufacture of dope shall be purified and give a negative potassium-iodide test at the end of 20 minutes, according to the standard method. The amount of cellulose nitrate used shall not be less than 55 grammes per litre of dope.

*Solvents.*—The volatile solvents employed should present no danger to the workmen applying them.

*Exposure Test.*—Dopes must comply with the following test. A square 12-inch frame, inside measurement, is covered on both sides with fabric, the fabric being tacked to the outer side of the frame under united tension, simulating the conditions employed in aeroplane manufacture. Four coats, or an equivalent, of dope to be applied to each side of the frame, each coat being allowed to dry thoroughly before the succeeding coat is applied. The frames are to be exposed on a roof in an unshaded horizontal position, one side being constantly uppermost. After 60 days of constant exposure no spontaneous cracking of the doped surface should be apparent, and after remaining 1 hour at a temperature of 70° to 80° F. the film shall not crack and shall have a decided ring. This test shall be made comparatively with a dope that has previously passed the test, and shall be in effect until a mechanical test is adopted.

*Shipment.*—Dope shall be shipped in metal cans, metal or wooden barrels, or earthenware containers. Inspection of the containers shall be permitted to insure against the accidental introduction of foreign

material. The container shall be marked with the date of manufacture, serial number, gross, tare, and net weight.

TESTING THE DOPES.

*Acidity.*—A 500 c.c. beaker, containing about 200 c.c. of water, is counterbalanced on a large balance, which is adjusted to 0·01 gramme by adding or removing water. About 10 grammes of dope are poured into the water and the increase in weight noted. This is rapidly done to 0·01 gramme to diminish the solvent loss. The dope is stirred up and allowed to stand 10 to 15 minutes with occasional stirring. The liquid is decanted through a rather porous filter into an 800 c.c. beaker, and 150 c.c. of warm water added to the residue. It is allowed to stand 10 to 15 minutes with frequent stirring and poured through the filter into the 800 c.c. beaker. The residue is washed with 150 c.c. of warm water as before. A few drops of phenolphthalein are added and the solution titrated with tenth normal caustic soda to a colour that persists for ½ minute. Any satisfactory substitute method will be permissible on approval.

*Amount of Cellulose Nitrate.*—Pour 25 grammes of the dope into 100 grammes of chloroform, stirring constantly. Extract in a soxhlet with chloroform until all extractive material has been removed. Dry at 60° C. to constant weight and weigh.

*Film.*—Pour some of the dope on a glass plate and allow to dry spontaneously. The film may be examined for the general characteristics of transparency, coherence, strength, and flexibility.

## FINISHING VARNISHES

Although the use of pigmented dopes, paints, and camouflage colours have to some extent superseded the method of varnishing doped aeroplane fabric, yet it is still customary to finish machines in this manner.

The effect of varnishing is to give a smooth covering of high polish, which not only adds to the appearance, and protects the dope from the action of moisture, petrol, and oil, but also materially reduces the skin-frictional resistance ; a properly varnished surface has about the same resistance as that of plate-glass. In the case of streamlined shapes, struts, fast-flying wing sections, dirigibles, and similar bodies in which the skin friction is a large proportion of the total resistance, a varnished covering possesses very appreciable advantages over the rubbered or unvarnished surface.

The varnishes employed may be either of the oil, turpentine, or spirit base types, or mixtures of these.

The spirit varnishes are obtained by dissolving resins or gums, such as shellac, resin, mastic, and similar substances in alcohol, methylated spirits, naphtha, etc.

The oil varnishes are made from the resins and hardest gums, such as amber, copal, gum animi, etc., dissolved in an oil, such as linseed or walnut oil, treated chemically. When oil varnishes are left to dry in the air, they oxidize fairly rapidly and form a hard, thin coat.

Spirit varnishes dry rapidly in air (usually from 1 to 4 hours is required), but do not give such an elastic or durable coat as in the case of oil varnishes; the latter, however, require a considerably long time in which to dry, but are much more permanent.

For these reasons, oil and turpentine varnishes are preferred to spirit varnishes for doped fabric finishing work. The following is a typical finishing varnish composition*—

| | |
|---|---|
| Thickened refined linseed oil .. | 45–50 parts |
| Resinates of lead and manganese .. | About 5 „ |
| American turpentine .. .. .. | 45–50 „ |

About 2½ per cent. of a hard resin may be added if desired, and a mixture of turpentine and petroleum spirit may be used instead of the turpentine alone.

## Methods of Doping.

The fabric surfaces to be doped are stretched over the frames by hand and are sewn or tacked into place. The dope is then applied by means of a wide, flat, fairly stiff bristle brush of about 4 inches width; it is essential that the bristles be fixed in such a manner that they are not affected by the dope constituents, and for this reason a metal-shrouded riveted camel-hair brush is considered about the best.

The dope (which is stored in large drums) is contained, for the doping operations, in a special design of dope-can, which minimizes the evaporation of the volatile solvents and therefore maintains a fairly constant viscosity.

Fig. 112 shows a type of dope-can recommended for the purpose; it possesses the advantage of minimizing evaporation

* Recommended by the British Aeroplane Varnish Co.

and of squeezing the brush slightly when it is withdrawn, so that it prevents it holding an excess of dope.

Doping should be carried out in a properly ventilated room, the temperature of which is maintained at from 65° F. to 70° F.; if the temperature is lower than this the dope

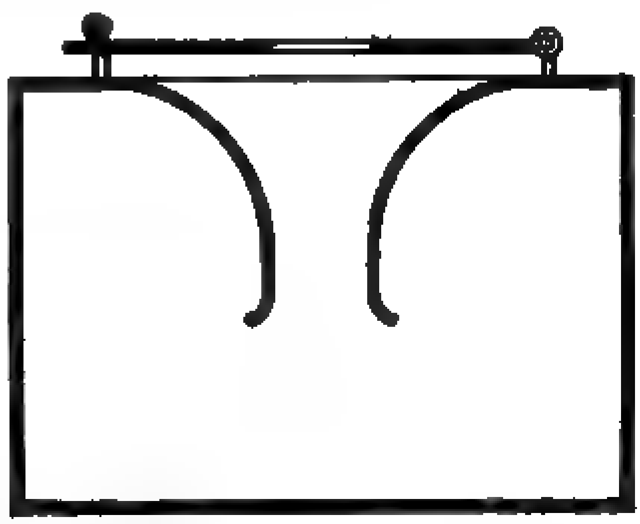


FIG. 112.—SHOWING PRINCIPLE OF DOPE CAN.

FIG. 113.—TYPICAL FORM OF DOPE CAN.

not only takes longer to dry but becomes patchy and often shows a white, curdy appearance.*

The fabric should be quite free from any oils or fats; occasionally the fabric is found to contain spots of the lubricating material or tallow used in the looms during weaving. The effect of lubricants of this type is to prevent the dope

* White spots are also due to the use of too thick a dope, or to moisture inclusion.

from impregnating the fabric and from drying properly; the dope when dry has a tendency to peel off.

The first coat of dope should be applied in such a manner that it is worked or rubbed well into the fabric, more especially over the fabric that comes into contact with the woodwork, so that the fabric adheres to same. By rubbing the first coat well in, the formation of small air-bubbles* between the cross-threads of the fabric is prevented.

The second coat of dope is applied after the first is dry; this is usually a matter of from 3 to 5 hours.

Subsequent coats of dope are only lightly applied, any roughness being removed by rubbing the surface with a clean piece of soft rag; the use of sand or glass-paper should be obviated, as it tends to cut the fabric and to destroy the dope film.

The number of coats of dope required depends upon the type of dope and varnish used, but usually from four to six coats are applied; a good guide, should the means for microscopic or other examination not be available, is to dope until the weight of the structure is increased by from 1 to 2 ounces per square yard.

### The Ventilation of Dope Rooms.

Although the use of tetrachlorethane dopes (which gave rise to several fatal cases of toxic jaundice) has been abandoned, yet the volatile constituents of dopes such as acetone substitutes, amyl acetate, benzol, etc., are known to have an unpleasant effect upon the human system, causing sleepiness, dryness of the throat, and sickness. It therefore becomes very necessary to adequately ventilate dope rooms in such a manner that these fumes are drawn off before they can do any harm, and a fresh supply of warm air admitted; the Home Office stipulate, in this connexion, that the air of dope rooms must be changed 30 times per hour.

A common method of heating and ventilating dope rooms

* The presence of air-bubbles causes eventual sagging of the fabric.

consists of gratings or suitable air exits placed at about the ground level (dope fumes, being heavier than air, naturally tend to sink) and provided with extraction, exhausting, or propeller type fans, which draw the fumes away. The fresh air may be delivered through ducts placed at least 10 feet above the ground, or through properly placed openings in the walls, on the opposite side to the exits ; the heating may be effected by drawing the air through steam-heated pipes, hot-water pipes, or by radiators placed near to the air inlets. In some cases the fresh air is heated and delivered in a similar manner to that employed in large factories, namely, by forcibly discharging it through large metal pipes placed well above the floor. The inlet air should be quite dust free, cheese-cloths or filters being employed for this purpose.

The ceiling of the dope room should be at least 10 or 12 feet from the floor, and should preferably be of a non-conducting material, in order to minimize heat losses ; if the dope room is too high, on the other hand, it will not be economical to change the air the minimum of 30 times an hour as required by the Home Office.

Figs. 114 and 115 show two typical schemes for heating and ventilating the dope room. In Fig. 114* the air inlet is provided with a regulating flap dust-trap compartment, the air being drawn past steam-heated radiators placed near the ceiling, whilst the suction fan is placed high up for convenience, and is provided with a suitable guide-duct ; it is, of course, more economical to exhaust the fumes at ground level than to lift them in order to expel them.

Fig. 115 shows an alternative method, in which heated air is delivered by means of large galvanized iron pipes, and the fumes are exhausted through a grating at ground level.

## The Spray Method of Varnishing and Painting.

A method which appears to be finding favour in connexion with the varnishing of doped surfaces is that in which the

* By courtesy of *The Ministry of Munitions Journal*, Dec., 1917.

varnish is sprayed through a suitable nozzle, or pistol, by means of compressed air.

For varnishing or painting small surfaces, the pistol is provided with a receptacle for the varnish, pigment, or paint,

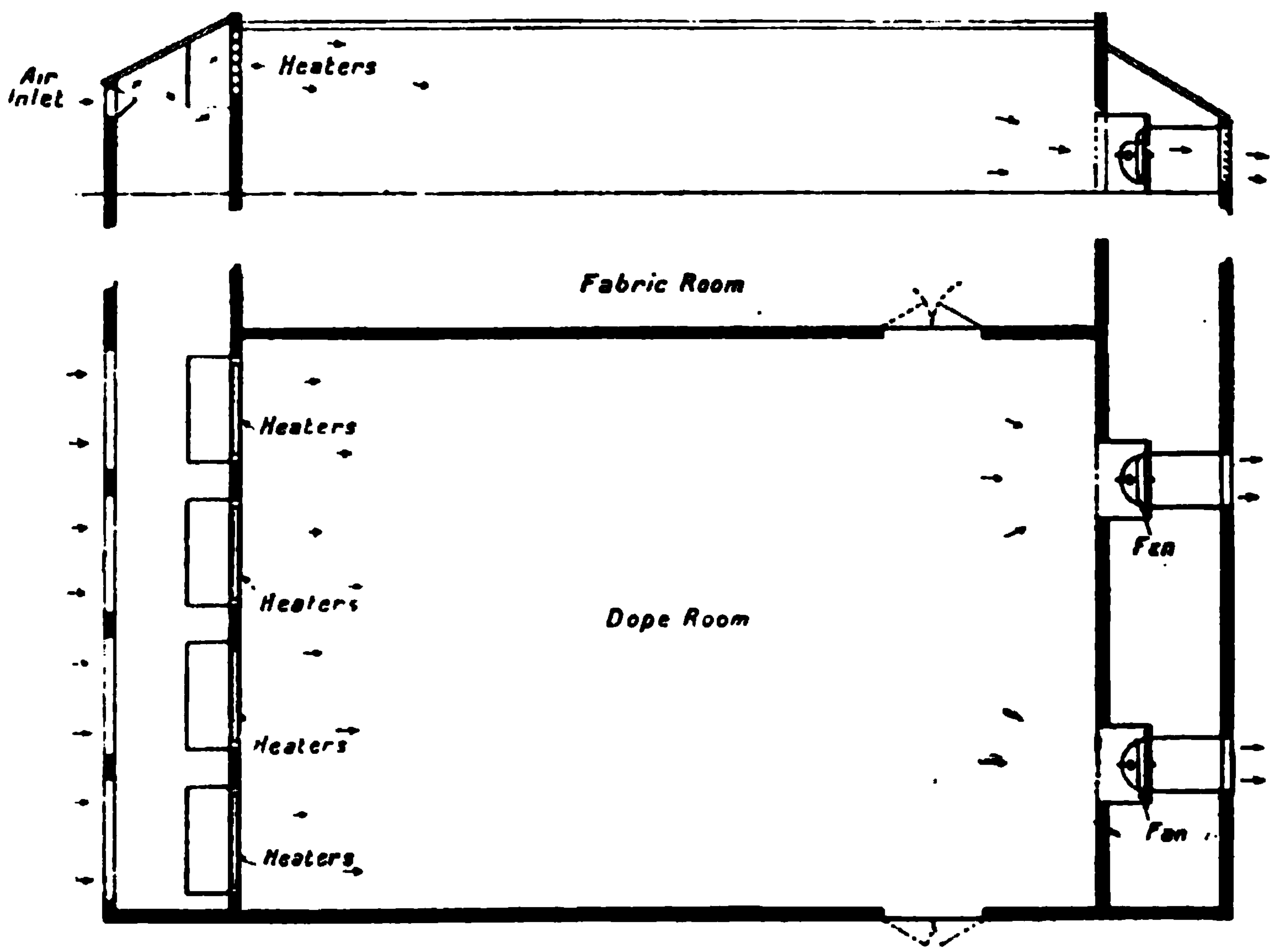



FIG. 114.—ILLUSTRATING METHOD OF VENTILATING DOPE ROOM.

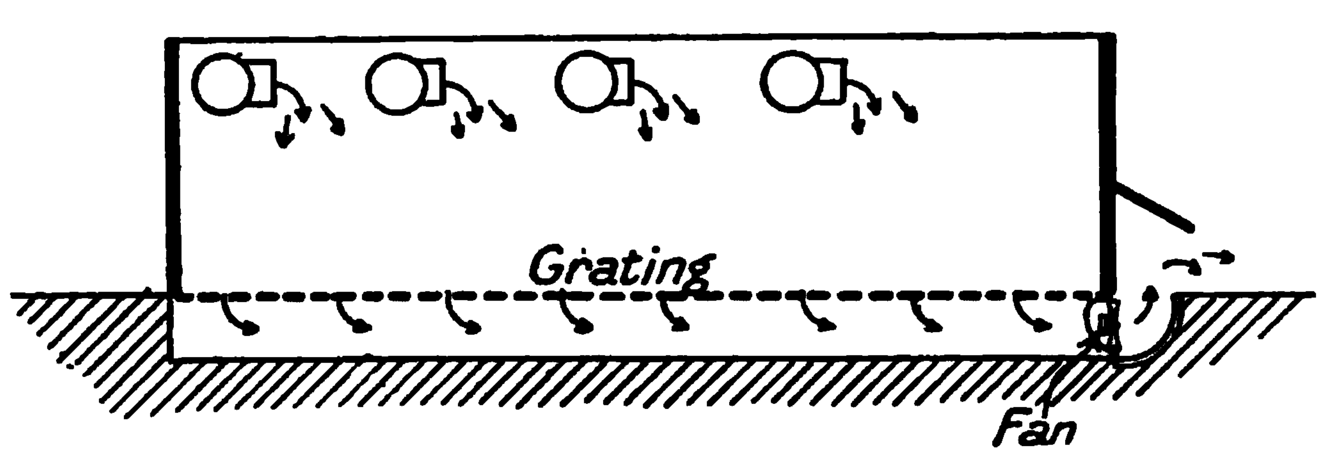



FIG. 115.—ALTERNATIVE METHOD FOR VENTILATION.

which fits on to the pistol itself, as shown in Fig. 116. For large areas it is necessary to use another type or adaption of pistol, in which the receptacle is replaced by a flexible tube supplying the liquid to be sprayed from a large reservoir, pressure being used to force the liquid up.

Figs. 117 and 118 illustrate a typical spraying pistol* of this type, showing the trigger mechanism controlling both the spraying air-valve and the needle-valve in the nozzle; in this manner both the air and liquid supplies are controllable in one operation.

Fig. 116.—Spraying Pistol.

The air escapes around a conical jacket which surrounds the liquid-delivering nozzle, and in escaping it catches up the liquid and converts it into a fine spray.

Air pressure is obtained by means of a portable compressor set of about 2 to 3 horse-power, two sprayers being workable with this set.

The air pressure required for spraying finishing varnish or P.C. 10 varnish varies from 30 to 55 pounds per square inch in the different types of spraying pistol.

* "The Aerograph" form.

Fig. 117.—Showing Operation of Spraying Pistol.

Fig. 118.

The nozzle should be held at from 8 to 10 inches from the work, and by moving it at an uniform speed a very even coating can be obtained of about 2½ to 4 inches width; for varnishing or pigmenting aeroplane fabrics the structure should be fixed in a vertical position, and the spraying commenced in horizontal layers, beginning at the top and working downwards.

By the use of the spraying method the amount of varnish or paint required per square yard is only a little over one-half of that used by the brush method; moreover, it is considerably more uniform and the operation takes only from one-third to one-half of the time. Unskilled labour can be employed with this process without affecting the uniformity or economy of the results obtained.

The amount of finishing varnish required to cover 40 square yards, using the compressed air supply type of pistol, shown in Fig. 118, is about 1 gallon.

This method is also applicable for doping balloons and aeroplanes, but care is necessary to ensure the proper viscosity and consistency of the dope. It is also used for varnishing the insides of shells, bombs, and mines, for enamelling bicycles, painting motor car bodies, and numerous other purposes.

# CHAPTER IX

# GLUES AND GLUING

## GLUES

THE term " glue " is widely applied to adhesives which possess the property of joining two surfaces together, and the adhesive may be either of vegetable, mineral, or animal origin; the present remarks will be chiefly confined to the latter type of glue.

Vegetable glues include starch glues, varnishes, resins, and gums. Thus a solution of starch, caustic soda, and water is used for paper adhesives, whilst a solution of gum arabic in water has gummy properties. Again, varnishes have been employed as adhesives, although the joints thus made are not very strong, and in aircraft work dopes are employed for fixing fabric to wood, for fabric bindings upon woodwork, and for patching fabric; for example, the frayed linen strips covering places where the fabric is joined, sewn, or tacked to the wood are invariably fixed with dope.

### Types of Glue.

As previously mentioned, there is a large and somewhat indefinite variety of adhesives which might be included under the heading of " glue."

Commercial glues, however, may be divided into fairly distinct classes according to their origin and manufacture. Amongst the more important of these glues the following may be mentioned—

(1) ANIMAL GLUES, comprising—

(*a*) *Hide Glues*, made from the scraps and cuttings of tanneries, together with the sinews and fleshings shaved from the inner surfaces of skins. Hide glues are widely

employed in aircraft work and are considered to be more suitable than bone glues.

(*b*) *Bone Glues*, made from the heads, ribs, shoulder blades, and other bones of domestic animals; the bone tissues yielding a substance containing a large proportion of chrondin.

(*c*) *Hoof* or *Footstock Glue*, derived from the hoofs of cattle.

(2) Fish Glue, which is properly included in animal glues. It is derived from the offal, heads, fins, tails, and bones of fish, which are boiled at 230° F. until of a treacle consistency. The odour is destroyed by creosote or sassafras.

(3) Liquid Glues. Chiefly animal glues in the liquid or jelly state ready for use; usually made by adding water and a preservative, such as from 5 to 10 per cent. of carbolic acid, to melted glue. Some liquid glues contain acetic acid, alum, and alcohol. Liquid glues are in general inferior to solid animal glues.

(4) Marine Glue. A strong, black, hard glue made from indiarubber, naphtha, and shellac; the following is a typical composition—

| | |
|---|---|
| Indiarubber .. .. .. | 4 parts |
| Coal-tar naphtha .. .. | 34 ,, |
| Powdered shellac .. .. | 64 ,, |

Another form of this glue is made from ordinary animal glue dissolved in water, to which resin and turpentine are added.

(5) Casein Glues. These glues, which consist of casein, soda, silica, lime, and other mineral matter, are fairly widely used for plywood work, and occasionally for propeller laminations. Casein glues are supplied in the powdered form, and are rubbed up or mixed with water for use; the solution does not keep for more than a few hours after mixing, so that it must always be used fresh.

Casein is a constituent of fresh milk, in which it exists in a

state of suspension as colloid ; it can be obtained by filtration, and is probably a compound of lime and casein with a weak acid. About 85 per cent. of the protein of milk consists of this compound.

Casein can be obtained from milk either by treating the milk with an acid or by adding rennet. The effect of the acid is to split up the casein compound and para-casein is precipitated in the form of a curd. There is a marked difference in the properties of the acid and the rennet curd. The former contains no lime salts, since these are all dissolved by the acid, whilst the latter is more elastic and is not sticky.

The following is the result* of an analysis of pure cow's milk casein—

| | |
|---|---|
| Carbon | 52·9 |
| Oxygen | 22·8 |
| Nitrogen | 15·6 |
| Hydrogen | 7·0 |
| Phosphorus | 0·85 |
| Sulphur | 0·77 |

The following account of the manufacture of industrial casein is taken from the article given in the footnote—

"There are two general methods for the precipitation of para-casein: the first and more important is the acid, or natural sour process; the second is the rennet process. This latter method has not been approved by the (American) Government. Acid curd is precipitated from the skimmed milk by lactic acid, or by either dilute sulphuric or hydrochloric acids. The yellowish precipitant is re-dissolved in alkali (sodium bicarbonate) and re-precipitated by dilute acetic acid. The curd then is well washed and pressed, after which it is stirred to pulp with water (100 parts curd to 50 parts water). When this operation is completed, it is steamed or cooked for 25 to 30 minutes in a wooden vat, with about 100 parts of a 1 per cent. solution of soda, to remove the lactic acid and butter fat. Upon heating, the mass forms a thin milky fluid, which is transferred to a separate vessel to

* "The Manufacture and Use of Glues in Aeroplane Construction." C. Boulton, *Aerial Age Weekly*, 5th May, 1919.

cool and there precipitated by dilute nitric acid. The casein collects at the bottom; the supernatant liquor is drawn off, and the casein is rinsed with water. The casein is allowed to settle in the water, which is then very gently drawn off. This operation is repeated until the wash water is neutral, when the casein is drained on filter-cloths, pressed, and dried on trays in drying chambers at 120° to 140° F.

"One hundred parts of curd yield 45 parts of purified casein, free from lactic acid and butter fat."

In the case of the glue manufactured by the Forest Products Laboratory,* the following method is adopted: One pint of gum arabic is dissolved in 5 pints of 40 per cent. commercial water-glass, or sodium silicate, and evaporated over a water bath until dry enough to grind. After it has been ground to 50 mesh, the silicate-gum arabic mixture is thoroughly mixed with calcium hydroxide of 150 mesh and casein of 40 mesh size, in the proportions of 40 parts casein, 25 parts alkali, and 25 parts gum mixture. This casein mixture dissolves readily in cold water in the proportions of 10 parts by weight of the glue mixture to 22 parts of water.

The following is an analysis of a well-known French propeller glue, known as Le Grandville—

| | |
|---|---|
| Casein | 36·00 |
| Calcium hydroxide | 23·80 |
| Sodium silicate | 17·00 |
| Gum arabic | 5·50 |
| Moisture | 5·30 |
| Calcium carbonate | 8·00 |
| Ammonia (free) | 1·25 |
| Iron, aluminium, and magnesium oxides | 1·50 |
| Undetermined | 1·65 |
| | 100·00 |

An analysis of a well-known Swiss casein glue is as follows—

| | *Per cent.* |
|---|---|
| Casein | 66 |
| Mineral matter (soda, lime, silica, and ammonia) | 23 |
| Petroleum | 1 |

* "Glue for Use on Aeroplanes." P. A. Houseman, *Journ. of Industrial and Engineering Chemistry.* Reproduced in *The Aeroplane,* 15th Aug., 1917.

Another type of casein glue used by plywood manufacturers consists of the following substances—

| | Per cent. |
|---|---|
| Casein .. .. .. .. .. | 66 |
| Lime, or borax .. .. .. | 34 |

Casein glues are fairly waterproof, and will withstand the water tests better than ordinary glues; they are not so strong, however, in shear or tension as ordinary glues.

These glues require from 1 to 3 days in which to set.

(6) WATERPROOF GLUES.—These glues are used for plywoods, aeroplane woodwork, propellers, and all woodwork exposed to the action of water. Ordinary glue in solution is precipitated by formaldehyde formalin, the powder formed being insoluble in water; if a very small quantity of formaldehyde (1 to 3 per cent.) be added to the glue solution in the hot state, just before using, the glue, when set, will be insoluble in water, and any remaining stock will be useless on this account.

A typical composition* for a water-proof glue is as follows—

| | |
|---|---|
| Dry glue.. .. .. .. | 100 pounds |
| Formaldehyde liquid .. .. | 0·5–1 per cent. |

It is also possible to render glue water-proof by adding a chromium salt, such as bichromate of potash, chrome alum, or chromate of lime to the glue solution; the glue does not, however, become insoluble until it is exposed to sunlight. This property is the basis of several photographic processes. The proper quantity of bichromate of potash to use is from 1 to 3 per cent. of the weight of the solid glue; the exact quantity, as in the case of formaldehyde, is a matter of experiment for each kind of glue.

The chromate must be dissolved in water and added to the hot liquid glue; if too much chromate is added the glue becomes stringy.

Other "water-proof" glues are obtained by adding substances such as resin, red ochre, boiled oil, and oxide of iron to the glue.

* "Glue," by G. F. Lull. See *The Aeroplane*, 23rd Jan., 1918.

Casein may also be termed a water-proof glue.

Many of the so-called " water-proof " glues, made to different pocket-book formulæ, are not truly water-proof, and should be carefully tested by hot and cold immersion for several hours before employing them.

(7) VEGETABLE GLUES OR PASTES.—These pastes are usually made from starch, flour, or rice powder, mixed with hot water ; they should be used soon after making, otherwise they turn sour, or become mouldy. The addition of a preservative such as oil of cloves will keep the paste fresh for long periods of time.

A good paste for leather, parchment, or paper may be made by mixing equal quantities of rice and flour with enough cold water to form a paste, and then boiling the mixture.

Another more permanent paste is made by dissolving three-quarters of an ounce of alum in a quart of cold water, and then adding enough flour to bring the whole to cream-like consistency. The mixture should then be brought slowly to the boiling point and a little powdered resin and a few drops of oil of cloves then added.

(8) FLEXIBLE GLUE.—Animal glue may be rendered flexible by mixing it with glycerine and water, to which molasses or sugar is added. This type of glue is used for leather and upholstery work, book-binding, printers' rolls, etc. A mixture of equal parts of glycerine and glue gives a fairly rigid flexible glue. The following is a typical recipe for flexible glue—

| | |
|---|---|
| Animal glue .. .. .. | 50 parts |
| Glycerine .. .. .. | 46 „ |
| Molasses, or sugar .. .. | 4 „ |

Water is added in sufficient quantity to give the proper degree of flexibility.

(9) ALBUMEN GLUES.—These are principally derived from egg and blood sources, although the preparation of many albumen glues is a trade secret.

In the case of egg albumen, it is the white of the egg which is employed, the yolks being carefully separated.

Egg albumen consists of 84 per cent. water, 11·9 per cent. albumen, 3·6 per cent. fat., etc., and 5 per cent. ash.

In the process of manufacture of this glue, the whites of the eggs are strained through the silk gauze lining of the drum of a centrifugal machine, and allowed to stand for about 40 hours. The albumen is then dried as quickly as possible in a dry air current or *in vacuo* at a temperature not exceeding 120° F., otherwise the albumen turns yellow. After from 3 to 6 hours the process is completed and the albumen is obtained in the form of thin, clear, elastic sheets. It is stated* that about 100 to 125 eggs are required for every pound of dry albumen.

Blood albumen is made from the fresh blood of cattle, which is spread in dishes of large surfaces but of little depth, until the fibrin of the blood and the pale yellow serum separate.

This serum, which is the part used, is strained through the silk lining of a centrifugal machine drum and allowed to stand for about 40 hours. It is then dried as in the case of the egg albumen, when it forms flakes varying in colour from grey to black, the former being the purer. It is stated that the blood from one cow will produce a little less than 1 pound of glue.

Albumen glues are applied hot and the same precautions taken as with other glues as regards the room temperature, application, and thinness of layer and pressure required.

Albumen glues come under the category of cements, in the true sense of the word, as their hardening is due to chemical action and not to evaporation, as in the case of ordinary glues.

Albumen glues, which are water-proof, and which are superior to hide and casein glues, are used in plywood manufacture ; the blood albumen glues are preferred to those derived from eggs.

* See footnote, p. 393.

## General Notes upon Glues.

The strongest and most widely employed glues are of animal origin, being made from hide, sinews, bones of domestic animals and fishes, hoofs, etc.

Animal glues are "colloids," or gelatinous products of the general formula $C_{76}H_{124}N_{24}O_{29}$; up to the present the subject of the constitution and physical properties of glue has not been properly investigated, so that the available knowledge is incomplete.*

True glue is impure gelatine, but in the manufactured form it differs from ordinary gelatine in that it is a hard, brittle mass, whereas gelatine is a kind of jelly with natural adhesive properties. Gelatine and glue are both derived from the same source, and resemble each other in composition; whereas pure gelatine may be regarded as the essential part of glue, the glue itself is in reality an impure gelatine.

Gelatine is nearly colourless, tasteless, and odourless, whereas most glues are of marked colour and possess both taste and odour.

## Animal Glues.

Animal glues vary considerably in appearance and in their strength properties; the colours range from the nearly white, transparent (bleached), to a deep red or brown.

Glues of a red or brown colour owe their appearance to the presence of residues of the blood used in the clarifying process, or to the formation of a brown substance resembling casein in its properties. It is generally considered by carpenters and woodworkers that the red or brown coloured glues are stronger than those of a lighter colour, but when the bleaching of glue is properly carried out, its strength and permanence is appreciably improved.

It is possible, by suitably selecting the bleaching agents, to improve both the strength and keeping qualities of glue;

* "Glues, Gelatine, and Their Allied Products," Thos. Lambert. (Griffin & Co.)

for example, by using sulphurous acid the sulphates formed bleach the glue and increase the strength; or, again, the use of chlorine neutralizes the nitrogenous matter which would otherwise cause decay and thereby greatly improves the keeping qualities, but not the strength, of the glue.

In general, it may be said that reagents which increase the viscosity of the glue also improve its strength, and that low viscosities correspond with weakness.

Slow-drying glues are, in general, stronger than quick-drying ones. The addition of from 5 to 10 per cent. of phenol* to glue improves the strength of the joint, and slightly improves its heat and water resisting properties; the addition of 5 per cent. of phenol to ordinary aeroplane glue solutions is therefore beneficial. Ammonia† causes the glue to set more quickly, but it does not appear to affect the strength or waterproof properties appreciably.

### Preparation and Use of Glue.

Animal glues are supplied in the form of flat slabs or cakes of square or oblong shape in this country, but in the United States they are marketed in the flake or powder form.

In the cake form, the glue is broken into small pieces for use and these are soaked in cold water for a period of from 12 to 24 hours to absorb water, after which they are placed in the glue-pot, which should be of the porringer or water-jacketed type. The melting temperature of most glues is from 55° to 80° C., and the temperature should not exceed the proper melting point. The glue itself should be used as soon as possible, as it has been found that the effect of prolonged heating is to steadily weaken the glue.

Glue which has been several times re-heated is found to have its strength and endurance properties adversely affected; for this reason enough glue only should be melted for the work in hand.

* See p. 406.
† See Table CXXVI.

Glues should be applied thinly and evenly to the surfaces to be joined, and it is an advantage to roughen the surfaces with a fine toothing plane.

The temperature of the gluing room should be kept constant at about 70° F., and draught free; it is considered to be beneficial to slightly warm the wood to be joined, and to apply the glue in as hot a condition as possible.

The glue should be given some time in order to thoroughly soak into the pores of the wood, after which the parts should be clamped and put aside to dry; the clamps may be removed after from 12 to 16 hours, and the glued parts should be allowed another day before being put into use.

It has been shown that the strength of the joint is, within certain limits, independent of the dilution or concentration of the glue; the same results have been obtained with glue dilutions of 1 to 1, 1 to 1½, 1 to 2, and 1 to 3.

## The Effect of Glue upon Wood.

The liquid glue, when properly applied, fills up the pores and open vessels of the wood in the neighbourhood of the joint and acts as a kind of dove-tailing or interlocking agent between the respective pores of the two surfaces.

Fig. 119* shows a micrograph of a properly glued joint between two pieces of mahogany, as used in propeller work. The darker patches along the line of the joint show where the glue has filled up the grooves made by the toothing plane; it will be observed that the glue has satisfactorily penetrated the pores of the wood and has left a thin film or lining between the two pieces of wood.

The strength of the joint, it would appear from these facts, is dependent upon the kind of wood employed, that is to say, upon the grain, presence of pores and vessels, ducts, etc.

Fig. 120 is a micrograph, taken on a panchromatic plate, the glue being stained bright (acid fuchsine) red, of a mahogany

* See also "The Less Satisfactory Materials of Aircraft Construction." G. S. Walpole, *Aeron. Journ.*, Jan.-Mar., 1917.

FIG. 119.—MICROGRAPH SHOWING GLUED JOINT IN MAHOGANY.

FIG. 120.—MICROGRAPH SHOWING GLUED JOINT IN MAHOGANY.

joint, similar to the previous one, but taken across the grain, showing some of the large vessels nearly filled, and others with a glue lining. This illustration also shows the marks left by the toothing plane, two pairs of grooves being shown.

**Testing of Glue and Glued Joints.***

The subject of the proper testing of glue has received much attention in connexion with aircraft work, and a series of tests have been specified by leading authorities, such as the A.I.D., the Society of Automotive Engineers, and others.

The testing of glue involves—

(*a*) A Shear or Tension test upon a suitably shaped wooden joint.

(*b*) A Dry Heat test in which suitably shaped test pieces are heated to a specified temperature (usually at 40° C. to 45° C.) for several hours, and are then tested in shear or tension.

(*c*) An Immersion test, in which the glued joint is immersed in water at about 20° C. for a specified period of from 12 to 36 hours, after which it is tested in shear or tension.

Other tests that are sometimes specified include a *low temperature test*, at from –20° C. to 0° C. for several hours, followed by the testing of the joint, and a *humidity test*, in which the joint must support a given load in a warm saturated atmosphere for a stipulated period of time.

Fig. 121 illustrates five different types of test upon glued joints which are commonly employed,† including (1) Transverse, (2) Bending, (3) Tensile, (4) Oblique Tensile, and (5) Shear Tests.

Tests Nos. 2 and 3 resemble those specified for aircraft glued joints in this country, the wood used being dry American walnut. Test No. 5 is similar to that recommended by the Society of Automotive Engineers,‡ the shearing area

* Fuller Information will be found in "Glues used in Airplane Parts." Report No. 66, U.S. National Advisory Committee for Aeronautics, 1920.

† *Aeron. Journal*, Jan.-Mar., 1917.

‡ See Specification for Glue, p. 407, *et seq.*

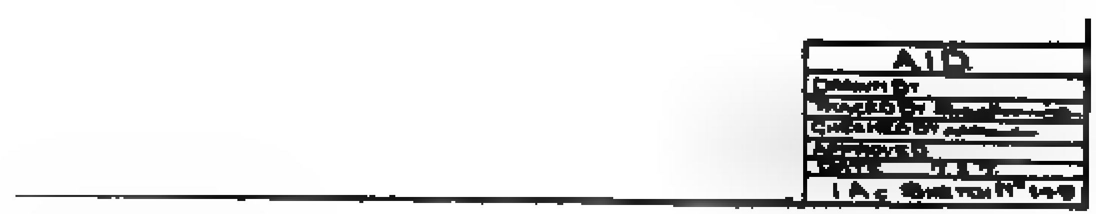



FIG. 121.—GLUE TESTS.

dimensions (in either the single or double stress tests) being 2 inches square (4 square inches), as shown in Fig. 121.

The results of a number of tests* upon glued joints in single shear, when subjected to ordinary heat, and immersion testing conditions are given in Table CXXVI.

For these tests, pieces of dry American walnut, giving a shearing area of 4 square inches, the dimensions of the test pieces were 9 inches × 2 inches × $\frac{3}{8}$ inch.

The wood was exposed for 24 hours at a temperature of 35° C. before making the joint, and each of the glue solutions was applied at a temperature of 60° C., the joints being afterwards clamped under moderate pressure for 48 hours, and finally given another 24 hours, unclamped, before testing. Duplicate tests were made upon each type of glue. Three tests were made upon each kind of glued joint, namely—

(1) An ordinary single *shear test* in a tensile testing machine.

(2) A *heat test*, in which the joints were subjected to dry heat in an electrically heated oven for 2 days at 45° C., after which they were tested in single shear.

(3) An *immersion test*, in which the joints were completely immersed in water at 20° C. for 12 hours, and then tested in single shear.

Tests were also made with moist heat and immersion, followed by dry heat, but were discontinued, as the results showed that all of the glue tested gave very low results.

The usual method adopted in commercial work, in the case of propeller glues (which are of the highest possible quality), is to glue up a propeller, balance it in the ordinary way, and spin same at the same or a higher speed than it would be required to run at, upon the aeroplane engine.

The highest grades of propeller glue give a shearing strength of from 1800 to 2400 pounds per square inch ; this is, in general, considerably higher than the shearing strength along the grain of the wood itself. After immersion in warm water

* "Glue for Use on Aeroplanes," P. A. Houseman. *Aviation*, 1st July, 1917.

for about 24 hours the strength diminishes by from 20 to 50 per cent.

The bending strength value of high grade propeller glues, as tested by the method No. 2 (Bending), Fig. 121, is about

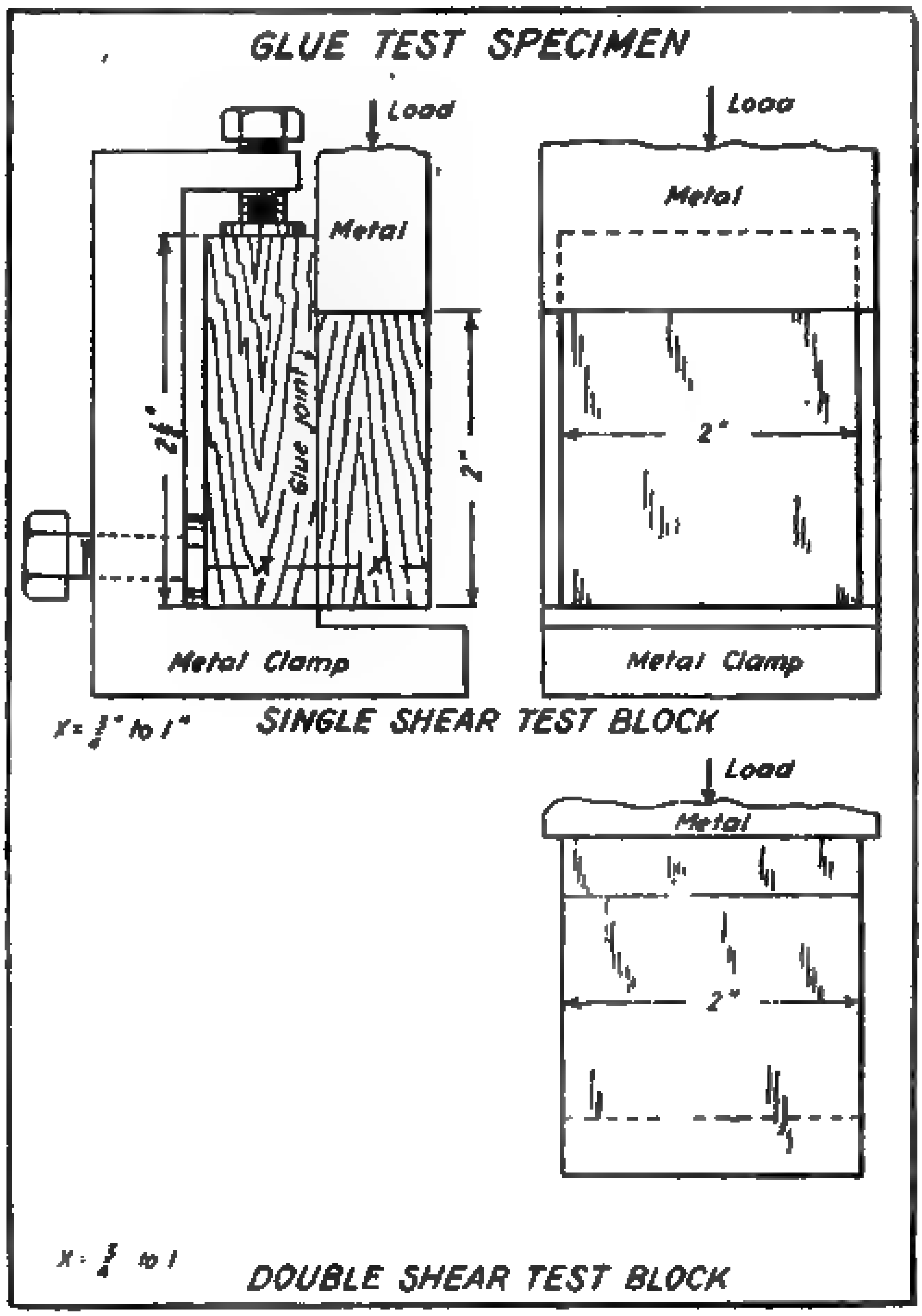



FIG. 122.—SOCIETY OF AUTOMOTIVE ENGINEERS' GLUE TESTS.

1100 pounds per square inch, for joints 1 inch long by 2 inches wide, and about 850 to 950 pounds per square inch for the lower grades of aircraft glues.

The tensile strength of a good propeller glue is from 180 to 270 pounds per square inch, but in exceptional cases higher values than these are obtained.

## TABLE CXXVI.

### TESTS UPON GLUED JOINTS. (Houseman.)

*Regular, Heat, and Immersion Test Results.*

| *Glue Tests.* | *Regular.* | | *Heat.* | | *Immersion* | |
|---|---|---|---|---|---|---|
| Gelatine *A* .. .. .. | 644 | 627 | 459 | — | 504 | — |
| Gelatine *A* + 5 per cent. phenol | 532* | 616 | 476* | 627 | 621 | — |
| Gelatine *A* + 10 per cent. phenol | 677* | 845 | 369 | 487 | 560 | 660 |
| "Propeller" glue .. .. | 464 | — | 470 | 464 | 540 | 504 |
| "Propeller" glue + 5 per cent. phenol .. .. .. | 526 | 593 | 395* | 506 | 553 | 560 |
| "Propeller" glue + 10 per cent. phenol .. .. .. | 610 | 632 | 315 | 429 | 560 | 565 |
| "Scotch" glue .. .. .. | 548 | 571 | 448 | 470 | 448 | 470 |
| "Scotch" glue + 5 per cent. phenol .. .. .. .. | 688* | 723 | 425 | 425 | 532 | 548 |
| "Scotch" glue + 10 per cent. phenol .. .. .. .. | 694 | 694 | 414 | 453 | 436 | 476 |
| Gelatine *A* .. .. .. .. | 627 | 644 | 459 | 565 | 504 | 549 |
| Gelatine *A* + 2 per cent. ammonia | 610 | 655 | 616 | 688 | 800 | 875 |
| "Propeller" glue .. .. | 464 | — | 464 | 470 | 540 | 504 |
| "Propeller" glue + 2 per cent. ammonia .. .. .. | 520 | 532 | 580 | 609 | 648 | 783 |

The figures represent breaking stress in pounds per square inch of glued surface of the standardized joint. Breaks in the wood are indicated thus *.

## TABLE CXXVII.

### THE HOLDING POWER OF GLUE. (Kempe.)

| *Wood.* | *Holding power (pounds per square inch).* | |
|---|---|---|
| | *Across the grain, end to end.* | *With the grain.* |
| Beech .. .. .. | 2133 | 1095 |
| Elm .. .. .. | 1436 | 1124 |
| Oak .. .. .. | 1735 | 568 |
| Whitewood .. .. | 3149 | 341 |
| Maple .. .. .. | 1422 | 896 |

## Specifications for Aircraft Glue.

### (*Society of Automotive Engineers.*)

PROCESS SPECIFICATIONS.

Tests at aeroplane factory are made to determine the strength of glue joints under the average conditions prevailing in the glue room. Tests shall be made on representative woods used by the manufacturer concerned. The glue test specimen shall be made of three boards ¾ to 1 inch thick, 4 feet long, and 5½ inches width. The gluing must represent actual practice, and no special precautions other than those ordinarily used shall be taken in preparing the glue or wood for the test specimen. The glueing shall be performed by the employees of the aeroplane factory who are accustomed to handling this kind of work. No protective coating of any kind shall be applied to the wood surfaces or to the finished specimen. This specimen shall set not longer than one week. The 4-foot specimen shall be cut lengthwise and 10 shear blocks cut from each half, according to the dimensions given. The shear blocks shall be tested as follows—

(*a*) Ten of the shear blocks shall be tested immediately after sawing. The strength of the glue in shear shall not be less than that of the wood.

(*b*) Ten of the shear blocks shall be soaked in water at 20° C. for 15 hours, and tested within 30 minutes after removal from the water, without any preliminary drying. The strength after soaking shall not decrease more than 60 per cent.

The required strength shall be obtained for 80 per cent. of the samples tested under each condition. A rejected propeller may be substituted for the 4-foot specimen specified above.

The tests at the aeroplane factory shall be in the presence of an inspector for the Signal Corps regularly stationed at the factory and familiar with the methods employed there. A test shall be made whenever a brand of glue is changed or a change is made in the method of gluing which, in the opinion of the purchaser's inspector, is important enough to warrant a test.

MATERIAL SPECIFICATIONS.

*General.*—This specification covers all glue for propeller construction and for splices of important structural members, such as longerons and beams. For all other work where woods of low shearing strength are used, any glue recommended by a reputable glue manufacturer can be used.

*Quality.*—The glue must be a high-grade hide glue, sweet, and free from any deleterious substances. The glue shall be compared to a standard sample for adhesiveness, jelly strength, viscosity, grease, and foam. The standard sample may be obtained from the Director, Forest Products Laboratory, Madison, Wis.

*Tests for Adhesiveness.*—The glue manufacturer may compare his glue with the standard sample by any methods he desires. The tests by the Government, however, will be made as follows: The strength test will be made by gluing together two pieces of maple or birch, 1 inch thick, having a shearing strength of at least 2400 pounds per square inch. This will require wood having an air dry weight of about 50 pounds or more per cubic foot, and a moisture content of from 8 to 12 per cent. These will be tested by shearing them in a testing machine. The glue will be mixed in proportions of two parts of water to one part of glue, unless otherwise recommended by the glue manufacturer. It will then be melted in a water bath and applied to the wood at a

temperature of about 60 per cent. (140° F.). After gluing, the test blocks will be held in clamps and allowed to stand for six additional days. They will then be finished, so that the blocks, when ready to test, will have a glued joint 2 inches square, and will be of the same shape shown in the sketch. When tested in this way no block shall fail under a load of less than 2200 pounds per square inch, and the average shearing strength shall be at least 2400 pounds.

*Jelly Strength.*—The jelly strength will be determined upon a mixture containing twelve parts of water to one part of glue. The glue will be soaked and melted as described under "Adhesiveness," then allowed to stand overnight in a refrigerator at a temperature of 5 to 10° C. (40 to 50° F.). The relative strength of the standard sample and the manufacturer's sample will then be determined by pressure with the finger immediately after the samples are removed from the refrigerator.

*Viscosity.*—The viscosity will be determined as in an Engler viscosimeter, upon a sample containing one part of glue to five parts of water, soaked and melted as described under "Adhesiveness." Two hundred cubic centimetres of the glue mixture will be run through the viscosimeter at a temperature of 60° C.

*Grease.*—The relative amount of grease present will be determined by mixing dye with some of the sample remaining from the viscosity test painting it on unsized white paper, and observing the appearance.

*Foam.*—The foam will be tested on the sample used for viscosity. The sample, heated to 60° C., will be beaten for 1 minute with a power egg-beater, or similar instrument, and allowed to stand 1 minute or until the height of the foam can be measured.

*Odour.*—The odour of the glue when in the hot solution must be sweet, and must remain sweet for 48 hours; that is, free from any suggestion of deteriorating animal matter.

*Marking.*—The glue which has been tested and passed shall be barrelled in the presence of the Government's representative and marked with the run number, date of run, and inspector's stamp. The glue which is marked in this manner may be sold as certified glue, and its use will be permitted in aeroplane factories.

## Bureau of Aircraft Production Specification for Glues.

The following are abridged specifications for glues used in aircraft construction—

*Hide Glue Certified for Use in Aeroplane Construction.*—(1) The glue must be a high-grade glue, sweet and free from any deleterious substances. (2) The glue shall be tested in accordance with the methods previously outlined, by comparison with a standard sample furnished by the Forests Products Laboratory, for adhesiveness, viscosity, jelly strength, grease, foam, and odour. (3) The glue used in the adhesiveness test should be mixed with water in four proportions, by weight—

| | | | | |
|---|---|---|---|---|
| Water .. | 2 | $2\frac{1}{4}$ | $2\frac{1}{2}$ | $2\frac{3}{4}$ |
| Glue .. | 1 | 1 | 1 | 1 |

(4) That proportion of water which gives the greatest glue strength shall be used. For this best proportion no specimen may fail at a load less than 2200 per square inch, and the average shearing strength must be 2400 per square inch.

*Handling and Testing of Hide Glue.*—This specification covers the methods and precautions to be used in the proportioning, soaking, melting, and applying of hide glue. These have been given in detail in the section treating of hide glue. A shear strength test must be made to ascertain the quality of the glue and the character of the work being done. For test specimens, 1 inch boards, of the same class of material as used in the work on hand, shall be glued up under the same average conditions as those under which the regular work is conducted ; no special precautions may be taken ; these boards shall be clamped and dried, as for the usual shear test. Ten specimens, conforming to Fig. 1, shall then be cut out and tested immediately. In at least eight specimens the strength of the glue shall not be less than that of the wood.

*Casein for Casein Aeroplane Glue.*—(1) The casein shall be made from straight skimmed milk of low fat content and free from starch, dirt, and other foreign material or adulterants. (2) The casein shall be precipitated by lactic acid, sulphuric acid, or hydrochloric acid methods. (3) The precipitating temperature should be about 120° F., never more than 130° F. Only sufficient acid to secure a clear separation shall be used. The curd shall be well pressed, and dried without delay to prevent moulding. Casein made from mouldy curd will not be accepted. (4) With the sulphuric acid process of precipitation, the cooked curd method is preferred. The temperature of cooking shall be about 190° to 195° F. (5) All vats, cloths, and other apparatus employed in obtaining the curd must be washed each day the equipment is used. (6) The specifications as to the properties of casein and the proportions of some of its constituents follow closely the specifications suggested by the F.P.L. in the section on Casein Glues, though allowing in some instances slightly more leeway.

*Casein Glue for Airplane Construction.*—(1) The certified glue shall be in the form of a powder not coarser than 50 mesh. (2) It must consist principally of certified casein. (3) The manufacturer shall prepare definite instructions for mixing the glue, and when these have been approved they must be exactly followed. (4) The test for adhesiveness shall be made on four standard shear specimens, prepared and tested in the specified regular manner. (5) The average shear strength must be 2200 per square inch, and the minimum in any single case 1800 per square inch. (6) In a similar manner four more test specimens shall be made up and subjected to the "water test" previously described. (7) The average shear strength must be 1500 per square inch, and the minimum 1400 per square inch. (8) The casein, after certification, must be properly stored in a dry sheltered place, such as is required for the storage of all glue and casein.

*Application of Certified Casein Joint Glue.*—The specifications regarding the mixing and application of this glue and the precautions to be observed, are embodied in the sections describing these processes for casein glue.

## AIRCRAFT PROPELLER CONSTRUCTION

Aircraft propellers are made of a number of laminations of either black walnut, mahogany, maple, or ash,* glued together and afterwards shaped to the appropriate sections in order

* Occasionally two kinds of wood in alternate laminations, such as mahogany and ash, are used.

to minimize warping tendencies. The thickness of the laminations varies from about $\frac{5}{8}$ inch to 1 inch, and the grain of the wood runs lengthwise and parallel to the surfaces glued.

The construction of a laminated wooden propeller requires great care and skill for permanent and accurate results.

The boards or laminations of the propeller are cut to thickness and stored for at least three weeks under similar temperature and hygroscopic conditions to those of the glue room. The surfaces of the boards to be glued are then accurately planed to the required thickness and grooved with a fine toothing plane; in the best practice, after the laminations have been cut to the dimensions shown on the drawings, they are approximately weighed or balanced, and assembled so that the whole number of laminations cancel out any individual variations.

The gluing operation is performed in a dust-free, dry room, which is maintained at a constant temperature of about 70° F.

The best glues only are employed for this class of work, and these should be prepared in accordance with the maker's instructions, and only a sufficient quantity made up each time for the work in hand. The glue should not be boiled, nor continuously heated; used glue should not be re-heated or mixed with fresh glue.

It is usual to glue up the laminations two at a time, and to hold same in suitable clamps, commencing the clamping at the centre and working outwards. Each pair of laminations should be held in the clamps for at least 12 hours, the clamps being spaced at about 8 inches apart; the pressure of clamping should be about 140 to 160 pounds per square inch.

It is advantageous to warm the laminations to about 90° to 100° F. before applying the glue, in order to minimize the cooling effect upon the glue, when it is applied. The glue should be put on thinly, and about 4 or 5 minutes should be allowed for the glue to soak in before placing the laminations together.

The whole operation should be completed as quickly as

possible after the glue has soaked in ; about 8 or 10 minutes is the usual period allowed for each pair of laminations.

The lamination pairs are next glued together in a similar manner, and given from 10 to 12 hours to set, under the clamps.

Finally, the whole block of laminations is glued, and given about 24 hours in which to set ; it is not now considered

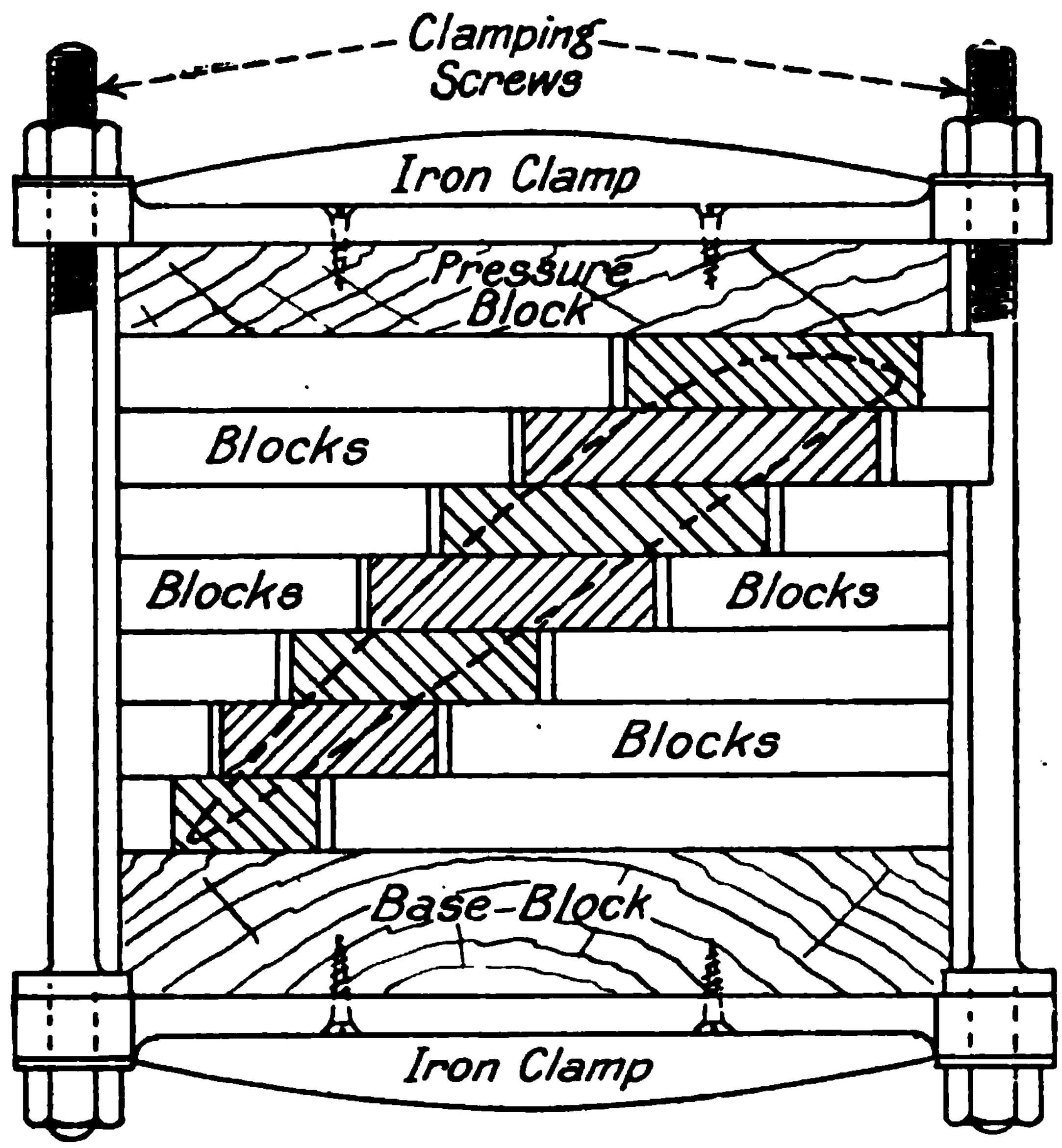



FIG. 123.—METHOD OF GLUING AND CLAMPING OF LAMINATIONS FOR PROPELLER.

necessary to peg the laminations, owing to the improvements in the materials employed and in the specified precautions taken.

After the clamps have been removed, the block is allowed another 40 to 50 hours in which to stand before the rough shaping is commenced. The rough shaping to plan form is done by a spindle or band-saw machine, but special profiling machines are sometimes employed to roughly shape the propeller to a standard shape, the final shaping being done

by hand. The propeller is held down upon a rigid table for clamping; for checking to templates for pitch angle and shape, a slate table is used. It is usual to allow about 4 days to elapse between the rough and the final shaping, in the propeller room.

The methods of finishing propellers, for protection, efficiency, and appearance purposes is described upon p. 472.

For fuller particulars of the method of balancing and testing propellers, their design, and general characteristics, the reader is referred to the work in the footnote.*

## Propeller Construction, I.A.S.B. Specifications.

The following are the specifications for the construction of aeroplane propellers, recommended by the International Aircraft Standards Committee; only the portion dealing with the materials and the gluing and finishing processes are given here—

*4E1, February*, 1918.

1. General.—The general specifications, 1G1, shall form, according to their applicability, a part of these specifications.

2. Materials.—(*a*) *Wood.* Woods for the manufacture of propellers for motors of more than 150 H.P., or more than 1600 revolutions per minute, are to be black walnut, true mahogany, or quarter-sawed white oak.

For machines under 150 H.P. and 1600 revolutions per minute, will also be allowed the use of West African mahogany, cherry, and birch. In any case, the manufacturer is not allowed to use a different material from that specified in the design without permission of the purchaser.

Thickness of the boards shall be ·75 to 1·0 inch, finished.

(*b*) The laminations of the propellers being of irregular shape, imperfections are allowable on edges and parts of boards that will be cut away in the shaping of the propellers, but the stock that goes into the propeller must be straight grain, free from curls, burls, and spiral grain, without knots, checks, dry rot, shakes, dote, or other imperfections, in entire accordance with the I.A.S.B. specifications Nos. 2W3–8 for the lumber.

Sapwood is not permitted in the finished blade, and is not allowed to extend in boss more than ·75 inch from the edge of the boss, and must in that case be sound.

(*c*) The physical properties of the wood shall be as specified in the I.A.S.B. specification, No. 3W1.

(*d*) Stock shall be dried to a moisture content of 7 per cent. by methods given in the I.A.S.B. specification No. 3W2.

* "Handbook of Modern Aeronautics," Chap. XVIII, "Airscrews," A. W. Judge. (The Library Press, Ltd.)

(*e*) The *glue* used shall conform to I.A.S.B. specification No. 2V2.

(*f*) Materials used for the *sheathing* of propellers for seaplanes may be the following—

(1) Sheet copper in conformity to I.A.S.B. specification 3N8.

(2) Monel metal sheet in conformity to I.A.S.B. specification 3N21.

(3) Linen in conformity to I.A.S.B. specification 2F3.

(4) Cotton fabric in conformity to I.A.S.B. specification 2F4, 2V1; the *filler*, to I.A.S.B. specification 2V2. The priming varnish shall be made by dilution of spar varnish with about two parts of turpentine.

3. MANUFACTURE.—(*a*) Each board shall be sawed and planed in accordance with blue prints. After planing they shall be glued promptly to avoid absorption of moisture, and great care must be taken to keep the wood under uniform conditions of temperature and humidity during all the operations.

(*b*) Boards shall be balanced before gluing, and heavy ends alternated so as to minimize the effect of variation in the density of the material.

(*c*) The boards shall be sawed for gluing in such a way that the grain follows the lamination of the propeller, avoiding any cross grain. At the same time, the boards shall be so arranged that the grain comes out on the edge, avoiding any flat grain.

(*d*) The practice of gluing edge pieces on to the boards in order to fill out the boss is forbidden, unless special permission is given by the purchaser. In case such permission is given, the laminations on both sides of the boss widener must be of the full width of the boss; that is, no two laminations which have wideners glued to them shall be adjacent. Both the lamination and the boss widener shall be corrugated at the joint to increase the gluing surface. No splice or "dutchman" shall be permitted on the blade of the propeller. Defective joints shall not be filled with glue. The practice of gluing a thin strip of veneer to the blades will not be allowed.

(*e*) The glue room must be kept at a temperature of 90° to 100° F. (32° to 38° C.), and an average pressure in gluing of 150 pounds per square inch (·11 kg./mm.$^2$) shall be maintained. Care shall be taken to ensure an even pressure on all parts of the glued surface for not less than 10 hours or longer, at the option of the purchaser. The pressure in the gluing process must not be removed before the expiration of 8 hours after it is completed. This period may be increased at the option of the purchaser.

(*f*) The propeller shall stand at least two days after gluing, nor shall it be finished in less than two weeks after roughing out.

(*g*) The surface of the propeller shall be smoothly sandpapered before the filler is applied, and the curvature shall be true and smooth throughout the length of the blade. Irregularities of contour are not permissible.

4. TOLERANCES.—(*a*) Propellers shall be inspected for pitch angle, alignment, blade form, and shape of section, as soon as they are finished by the manufacturer, and shall come within the following tolerance limits—

| | *Portion of blades more than 50 per cent. radius from axis.* | *Portion of blades less than 50 per cent. radius from axis.* |
|---|---|---|
| Alignment within .. | ·0625 inch | ·0625 inch |
| Error in fit of templets | ·01 × width of blade | ·02 × width of blade |
| Width of blade .. | ·075 × width of blade | ·01 × width of blade |
| Thickness of section .. | ·0625 inch | ·125 inch |

5. Sheathing of Propeller with Fabric.—(*a*) Before application the fabric shall be scrubbed thoroughly with hot water and soda, and after rinsing allowed to soak in hot water for 4 hours in order to remove all sizing from the cloth.

(*b*) The process shall be repeated until all the sizing is removed. The cloth shall be dried and applied to the blade in the glue room, with a standard temperature of 100° F.

(*c*) The blades shall be coated evenly with glue, and the cloth applied and ironed smooth, preferably with an electric iron.

(*d*) Twenty-four hours after gluing the fabric shall be given four coats of acetate dope, followed by two coats of varnish or enamel which conforms to I.A.S.B. specifications No. 2V1.

6. Sheathing of Propellers with Copper or Naval Brass.—(*a*) Metal sheathing shall be set in flush with the blade. Rivets of the same material as the sheathing shall be spaced over the area of the sheathing. They shall be applied in such a way as to fit tightly without splitting the wood, and shall be applied alternately from the face and the back. The rivets shall then be headed and filed to form a smooth surface. No rivets shall be driven closer than 1 inch from the propeller edge, except at the edge of the metal or in very small blades.

(*b*) A row of rivets about ·625 inch apart shall be spaced along the edge of the sheathing.

(*c*) The rivets shall not exceed ·085 inch in diameter and shall show a breaking load of at least 130 pounds (58·9 kg.) at the riveted end and 180 pounds (81·5 kg.) at the head end. The working stress due to centrifugal force shall not exceed 4266 pounds per square inch (3 kg./mm.$^2$).

(*d*) Sheathing shall be formed to the exact shape of the blade before any rivets are placed.

(*e*) The rivets shall be applied in such a way that they do not follow the line of the grain.

(*f*) When the work is complete the tip shall fit snugly against the wood. Buckling or lifting of the metal shall be considered ground for rejection.

(*g*) Sheathing shall be perforated at the extreme tip by four holes ·0625 to ·0938 inch in diameter, to allow the moisture to be removed.

7. Finishing of Propellers.—Propellers shall be finished by the application of 1 coat filler, 2 coats priming varnish, and 3 coats of spar varnish. Each coat should be allowed sufficient time to dry before the application of the next coat.

# CHAPTER X

# RUBBER AND ITS COMPOUNDS

## RUBBER

THE name " rubber " (or caoutchouc) is given to a number of different natural gums possessing certain common properties and constituents.

The chemical designation of rubber is rather indefinite, but its synthesis shows that it belongs to the terpene series of the general chemical formula $(C_{10}H_{16})_n$. In addition, many of the crude rubbers contain proteids, resins, hydrocarbons, and other substances, which have to be removed by different processes.

The constituents of rubber are contained in the milky fluid known as *latex*, which is obtained by the incision and tapping of the bark of tropical trees, vines, and shrubs which are very numerous in extent and which grow in a tropical belt comprising the countries of Mexico, Central America, South America, North Africa, Middle Africa, Java, Sumatra, Borneo, India, the Malay Straits, and the Philippines.

The latex, which is contained in vertical tubes or vessels in the inner bark, and which must be distinguished from the sap, has the appearance of thin cow's milk, and the crude rubber is obtained from it by the process of coagulation.

The materials employed to obtain coagulation vary with the different species of latex, and they include acetic acid, alcohol, air (fermentation process), blood, alum, lime, and lime juice. Certain agents, such as heat, sunshine, and smoke also promote coagulation.

Much of the best Para rubber is obtained by exposing the latex to the smoke of burning palm-nuts.

It is not possible to deal more fully with the various interesting processes of extraction of rubber, its classification and purification, in a work of the present nature, but for fuller

information upon the subject the reader is referred to the works and papers mentioned in the footnotes.*

## Purification of Rubber.

The crude rubber obtained by the coagulation process is next purified from mechanical impurities by washing, the rubber being washed in hot water and then disintegrated or torn into small pieces in a special machine through which water is constantly circulated. The rubber pieces are then dried by passing through rollers, during which process they become flattened out into thin sheets.

The next process consists in mixing with the crude rubber certain substances for hardening, filling, colouring, cheapening, and generally improving the rubber for its various commercial purposes. The number and the nature of substances employed varies with the type of the crude rubber, and depends upon its intended use.

Amongst the materials employed for cheapening and filling crude rubber, and at the same time improving its mechanical properties, may be mentioned sulphur, oils, resins, tars, whiting, white lead, talcs, barytes, clays, and rubber substitutes.

Fats and oils are also used to facilitate the mixing process, whilst bitumens such as tar, asphalt, and pitch are employed or binding, frictioning, and mixing purposes.

*References—

"Indiarubber as a Structural Material in Wood and Other Organic Structural Materials," C. H. Snow. (McGraw Hill Book Co.)

"Indiarubber and Gutta-Percha," Seeligman, Torrilhon, and Falconnet. (Scott, Greenwood & Co.)

"Crude Rubber and Compounding Ingredients," H. C. Pearson. (Indiarubber Publishing Co., New York, 1909.)

"Rubber," P. Schidrowitz. (Methuen & Co.)

"The Testing of Mechanical Rubber Goods," Circular No. 38 of the Bureau of Standards.

"Handbook for Rubber Engineers," W. Esch. Hamburg, 1912.

"Conductors for Electrical Distribution," F. A. C. Perrine. New York, 1903.

"The Manufacture of Rubber Goods," Adolf Heil and Dr. W. Esch. (Griffin & Co.)

"The Chemistry of Indiarubber," Carl Otto Weber. (Griffin & Co.)

Pigments such as lithopone, vermilion, zinc yellow, lamp-black, oxide of iron, antimony, arsenic and mercuric sulphides, graphite, etc., are incorporated with the fillers for the purpose of colouring the finished rubber product.

In the following notes,* particulars of the principal compounding materials used in rubber purification and manufacture are given—

1. Crude rubber, including hard, medium, soft, and very soft; also gutta percha, gutta siak, and balata. Rubber forms the basis of all good quality rubber goods. The kind or quality of the rubber determines to a large extent the quality of the cured finished article.

2. Reclaimed rubber; used mainly as a cheapener or filler. The properties of a reclaim and the properties which it has a tendency to impart to a stock, depend largely upon the kind of scrap from which it is reclaimed.

3. Rubber substitutes; used mainly as light gravity fillers.

4. Bitumens; tars, pitches, mineral rubber, and asphalt are all of similar nature. They are used mainly as cheap binders, or to facilitate the processing of the stock, such as mixing and frictioning.

5. Resins; used mainly as cheapeners and fillers and to exert a binding effect on the dry mineral powders.

6. Waxes; ceresin, paraffin, beeswax, ozokerite, used for special purposes, such as for obtaining a gas tight film and to obtain special results in hard rubber.

7. Fats and oils; cotton-seed oil, rosin oil, castor oil, paraffin oil, and vaseline used mainly to facilitate mixing and handling of the stock.

8. Mineral powders; this is such a large class that it should be considered under the following sub-classes, although some of the materials partake of the properties of two or more of these sub-classes:

(a) Vulcanizing agents: which include sulphur as the only one commonly used. Sulphur chloride is used in vapour or dip curing.

(b) Accelerators; which hasten and modify the combination of rubber and sulphur, including lime, magnesia usta, magnesium carbonate, antimony sulphide, litharge, and most other lead compounds.

(c) Special properties; some powders are added for the special properties which they give the compound. The most important is zinc oxide, with its peculiar toughening properties. Graphite and lamp black also belong to this class.

(d) Cheapeners or fillers; including whiting, barytes, talcs, and clays.

(e) Pigments, which are used principally for the special colour they produce, including lithopone, U.M. blue, English vermilion, zinc yellow, lamp-black, iron oxide, etc.

## Vulcanization.

Most of the commercial rubbers are produced by the process of vulcanization, which consists in mixing sulphur

* R. H. Upson. The Goodyear Tyre and Rubber Co.

with the pure or crude rubber and heating the mixture to a temperature above the melting point of sulphur.

The sulphur combines with the rubber, each rubber group of the formula $C_{10}H_{16}$ uniting with 2 atoms of sulphur, the resulting compound being stronger, more elastic, and less affected by temperature changes than the pure rubber itself.

The temperature of vulcanization is about 120° C. to 150° C., but it varies somewhat with the proportion of sulphur and the grade of rubber.

About 6 per cent. of sulphur, by weight, is employed in the vulcanization of the majority of articles used for mechanical purposes. For rubber shoes, coats, and other black rubber goods, about 3 per cent. of sulphur is used; whilst in the case of press-cured articles, such as rubber belts, about 8 per cent. is embodied. Vulcanite and ebonite contain larger quantities of sulphur, and require higher temperatures (above 140° C. to 150° C.).

Vulcanized rubbers are cleaner, stronger, and more stable than crude or pure rubber, and are more elastic; they are not affected by moderate temperature changes and are in every way more satisfactory for commercial purposes.

Various grades of rubber are produced by the vulcanization process, the *softer grades* containing smaller amounts of sulphur and requiring lower temperatures, whilst the *harder grades* contain greater amounts of sulphur and require higher temperatures.

*Soft grade* rubber is used for soft packings, tubing, and erasers.

*Medium grade* rubber is used for a variety of commercial purposes, including rubber sheeting, canvas ply tubing, hose piping, automobile and aeroplane tyres, balloon fabrics, shock-absorbers, surgical, and other goods.

*Semi-hard* rubber is a hard rubber intermediate between medium grade rubber and vulcanite; it contains more sulphur than the former grade, and is harder but not so

elastic ; it is used for rubber wearing surfaces, brake-blocks, buffers, etc.

*Hard* rubber compounds, such as *vulcanite* (red) and *ebonite* (black), contain higher proportions of sulphur and require higher vulcanization temperatures ; these materials are noted for their high insulation properties and are much employed in electrical work.

### Ebonite.

The resistivity of ebonite is of the order $10^{15}$ to $10^{18}$ ohm-centimetres at ordinary temperatures, and the surface resistivity is not impaired by exposure to sunlight. The dielectric constant is from 1·9 to 3·5. In small thicknesses of 20 mils, the dielectric strength ranges from 1700 to 3750 volts per mil, tested between 2 inch spheres, and 1000 to 2000 volts per mil when flat electrodes are used.

Mechanically, ebonite is brittle, but it can be worked, turned, and polished ; for turning, a high speed and sharp-edged cutting tools are required. The tensile strength is about 1000 pounds per square inch, and the compressive strength from 1800 to 2400 pounds per square inch.

The specific gravity varies from 1·20 to 1·25.

Ebonite is insoluble in water, but is attacked by oils, petroleum spirits, and ozone.

The process of vulcanization is also employed for filling cuts, mending punctures, and general pneumatic rubber tyre repairs, pure Para rubber being generally employed and a steam, electrical, or gas-heated vulcanizing plant.

### Physical Properties of Rubber.

Crude rubber is a tough, pliable solid, insoluble in water, and a bad conductor of electricity ; it possesses marked elastic properties which enable it to be extended or compressed through a distance equal to many times its original length, without permanent set.

Crude rubber is influenced by small temperature changes,

and when heated it becomes soft and "tacky"; it loses most of its elasticity when placed in boiling water, but hardens and becomes elastic again upon cooling.

It melts at about 120° C. into a viscous fluid, which does not harden again.

At low temperatures, most rubbers (crude, pure, or commercial) lose their elastic properties and become harder; at liquid air temperatures, rubber becomes very hard and may be powdered.

Crude rubber is insoluble in water and alcohol, and is only slightly affected by dilute acids, but dilute alkaline solutions exert a depolymerizing action upon rubber, rendering it soft, or even tacky.

Crude rubber is soluble in turpentine, petroleum spirits such as petrol, benzol, toluol, carbon disulphide, carbon tetrachloride, and other liquids, and solutions of crude rubber, or other grades, in some of these liquids, are used for pneumatic tyre repair purposes.

Crude rubber is subject to oxidation, which renders it soft and then hard and brittle; vulcanized rubber of all kinds also behaves in a similar manner, but to a less marked extent, and the phenomenon known as *perishing* is accelerated by exposure to heat and light.

Perishing may also be due to the filling constituents of the rubber itself. Rubber goods should be stored in cool, dark places, and should be well dusted with French chalk in order to protect them against the detrimental action of grease, oils, or fats.

The *electrical resistivity* of rubber is of the order of $10^{14}$ to $10^{16}$ ohms-centimetres, according to the quality, but increasing with the content of pure rubber.

The *temperature coefficient* is negative and unusually large, varying from 2 to 4 per cent. per degree C.

The *dielectric constant* of pure vulcanized rubber is from 2 to 3, and for compounds of rubber from 3 to 4.

The *dielectric strength* of rubber varies from 300 to 500 volts

per mil, and after long periods of electrification it appreciably diminishes.

The *specific gravity* of pure rubber varies from 0·93 to 0·97, and for rubber compounds from 1·7 to 2·0.

**Machining of Rubber.**

In many grades of rubber there is a certain amount of gritty material, which tends to take the edge off cutting tools ; for this reason it is necessary to harden the tools to a fairly high temper.

The most suitable tool for the medium or medium-hard compositions of rubber is that with a diamond point, ground a little round on the point and given a sharp rake.

The speed of machining depends upon the hardness of the rubber, being slower the harder the material.

Medium-soft and soft rubber cannot be machined satisfactorily, and are therefore ground in a lathe, using an overhead drum for driving the wheel, and fixing the arbor of the wheel to the tool rest.

Alternatively, a small electric motor-driven grinder can be used, and is probably more convenient.

**Mechanical Properties of Rubber.**

The mechanical properties of rubber depend upon the grade of rubber, that is to say, upon the relative proportions of the rubber, fillers, accelerators, and other ingredients.

Table CXXVIII gives the tensile strengths, ultimate elongations, and permanent sets of six different grades of rubber, tested by the American Bureau of Standards.*

The best grades of vulcanized rubber, used for their strength and elastic properties, have a tensile strength of about 2000 pounds per square inch, with an ultimate stretch of 600 per cent., that is to say, of six times their original length ; ordinary commercial rubbers are not so strong or elastic.

The stress-strain curve of rubber is not a straight line,

* "The Testing of Mechanical Rubber Goods." Circular No. 38, U.S. Bureau of Standards, 1913.

as the material does not obey Hooke's Law, so that there is no true elastic modulus.

For ordinary engineering purposes it is usual to take the mean slope of the stress-strain curve for a limiting extension of about 200 to 300 per cent., and to estimate the elastic modulus from this mean slope value. The value for the modulus, obtained in this manner, varies from 300 to 400 pounds per square inch for high-grade rubbers.

Indiarubber is an elastic body which exhibits relatively great changes of shape, or deformations, without undergoing any appreciable change of volume, so that, as the rubber is stretched, its sectional area becomes progressively less. The gauge length of a rubber strip in tension, unlike the case of ductile materials such as iron and steel, does not affect the percentage elongation.

In connexion with tensile tests upon rubber, it is difficult to hold the material in the grips, so that it is more convenient and equally suitable to test rubber in the form of rings slipped over two pins, one at each side of the testing machine grips.

Table CXXIX shows the results of tests upon indiarubber obtained by Dr. Winkler.

## TABLE CXXVIII.

### The Strength Properties of Rubber.

| Grade No. | *Tensile Strength, Pounds per sq. inch.* | | *Ultimate Elongation, per cent.* | | *Set,* per cent.* | |
|---|---|---|---|---|---|---|
| | *Longitudinal.* | *Transverse.* | *Longitudinal.* | *Transverse.* | *Longitudinal.* | *Transverse.* |
| 1 | 2730 | 2575 | 630 | 640 | 11·2 | 7·3 |
| 2 | 2070 | 2030 | 640 | 670 | 6·0 | 5·0 |
| 3 | 1200 | 1260 | 480 | 555 | 22·1 | 16·3 |
| 4 | 1850 | 1700 | 410 | 460 | 34·0 | 24·0 |
| 5 | 690 | 510 | 320 | 280 | 27·5 | 25·0 |
| 6 | 880 | 690 | 315 | 315 | 34·3 | 25·9 |

* After 300 per cent. elongation for 1 minute, with 1 minute rest. The set and the tensile strength were determined upon different samples.

## TABLE CXXIX.

### The Properties of Rubber in Tension and Compression.

| *Stress in pounds per square inch of original area.* | *Stress in kilograms per square centimetre of origianl area.** | *Percentage change of Length.* | |
|---|---|---|---|
| | | *Uniform Loading.* | *After lapse of period of time.* |
| − 7·11 | −0·5 | 3·6 | 3·6 |
| −14·22 | −1·0 | 7·6 | 8·2 |
| −21·33 | −1·5 | 10·9 | 11·5 |
| −28·44 | −2·0 | 13·9 | 14·7 |
| −35·55 | −2·5 | 16·3 | 17·3 |
| −42·66 | −3·0 | 18·5 | 19·8 |
| 7·11 | + 0·5 | 4·6 | 5·2 |
| 14·22 | 1·0 | 12·1 | 13·7 |
| 21·33 | 1·5 | 20·7 | 26·4 |
| 28·44 | 2·0 | 31·6 | 39·6 |
| 42·66 | 3·0 | 54·8 | 69·8 |
| 56·88 | 4·0 | 85·9 | 113·5 |
| 71·10 | 5·0 | 130·9 | 157·2 |
| 85·32 | 6·0 | 179·4 | 211·0 |

The above results are interesting as showing the lag between the stress and the strain, due to the time-interval effect; this is more clearly illustrated by the dotted lines in Fig. 124, which represent the stress-strain curves after an interval of time has elapsed, and the full line curves for the uniform rate of loading.

In this connexion it may be interesting to mention the results of some compression tests† upon a block of india-rubber, in which the diminution of height, or the compression strain, was noted after certain time intervals.

A compression strain of about 8 per cent. at the time of loading gradually increased to about 9 per cent. after the load had been on for 4 hours, and then very slowly increased to about 9·3 per cent. at the end of 26 hours. When the load

* Negative signs indicate compression tests, and positive, tension tests.

† "The Measurement of Stresses in Materials and Structures," E. G. Coker. Cantor Lectures, Roy. Soc. of Arts, 1914.

was removed, the rubber recovered its original height within 1 per cent., followed by a slow recovery which, at the end of another 14 hours, brought the block within about 0·33 per cent. of its original height.

Reverting again to the results given in Table CXXIX, and shown in Fig. 124, it will also be noticed that, for the same stress value, the compression strains are smaller than the

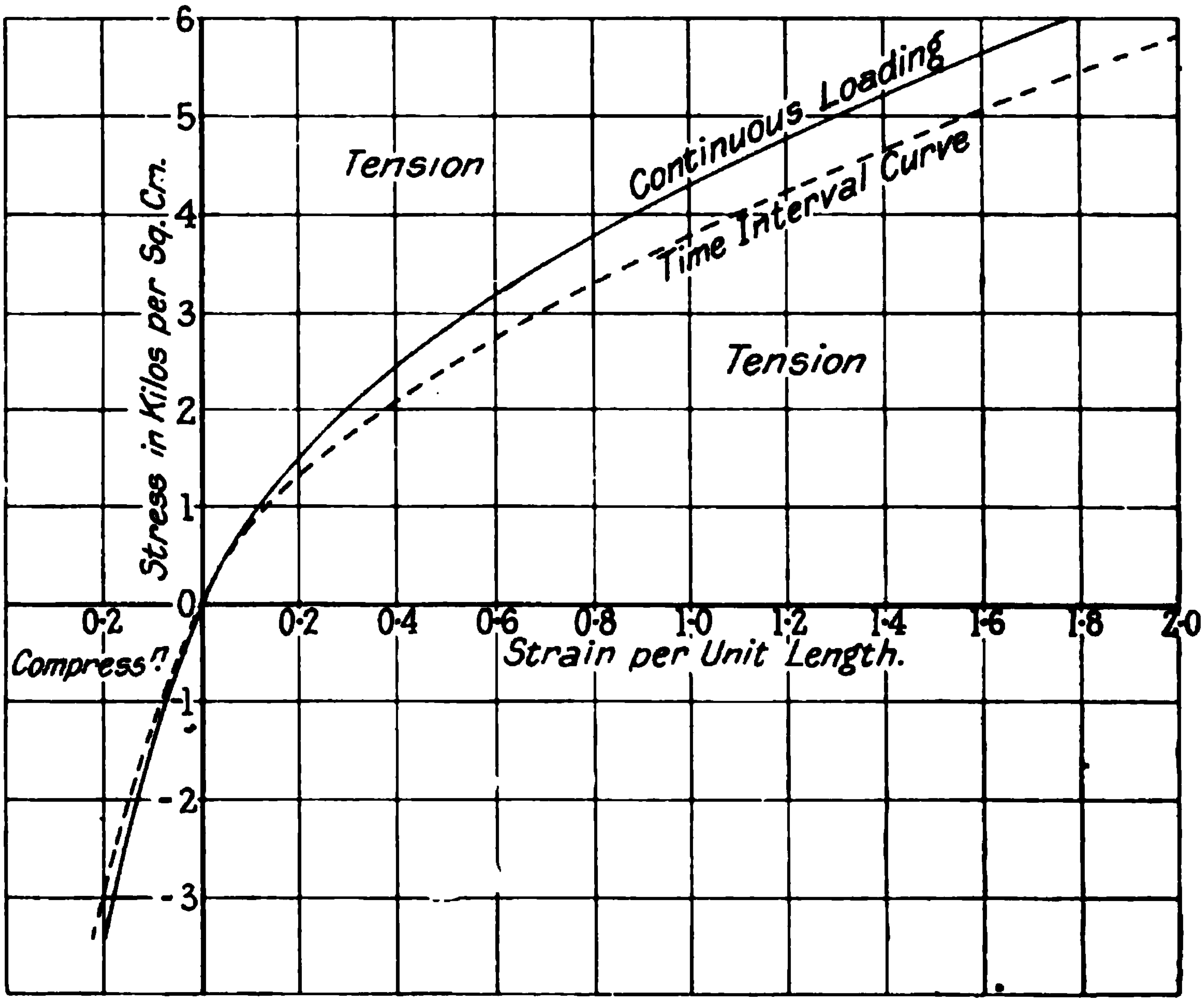



FIG. 124.—STRESS-STRAIN CURVES FOR RUBBER.

tension ones; the stress-strain curve in each case being a curved line and not a straight one.

If the elastic modulus be calculated from the ratio of the stress (in Columns 1 or 2, Table CXXIX) to the strain (in Columns 3 or 4), the results obtained will be found to be variable, due to the fact that the stress given is reckoned upon the original area, and not the actual corresponding area.

The values of the modulus, reckoned on the actual area, and the elongation per unit of stretched length, are more

uniform, and the mean values for compression and tension, in the above-mentioned tests, are 195 and 162 pounds per square inch respectively. The maximum values for the ranges of stress taken are 222 and 373 pounds per square inch respectively.

**Hysteresis Effect of Rubber.**

The most advantageous property of rubber, from the point of view of its use for springing and shock-absorbing members, is its relatively high hysteresis factor, the area of the hysteresis loop, which represents the amount of energy capable of being stored up in the material, being large.

The amount of energy absorbed by rubber is far greater than in the case of other common materials, owing to its greater stretch. Thus, good indiarubber can absorb from 500 to 1000 feet pounds of energy per pound weight, whereas spring steel is only capable of absorbing from 10 to 20 feet pounds per pound weight.

The work lost in hysteresis in low grade rubber may be as much as 70 per cent. of the work done upon the first extension. For higher grades of rubber, the hysteresis loss varies from 35 to 40 per cent.

Low grade rubbers are not, however, suitable for shock absorbers, owing to their lower ultimate stretch, rapidly perishing properties, and relative weakness under repetitions of loading.

When an aeroplane, having rubber shock absorbers, lands, the rubber takes up the first landing shock, and on this first cycle the hysteresis loop is large, and the aeroplane rebounds with only about one-half of its initial landing energy. During the subsequent running over the ground a rapid succession of bumps will cause the rubbers to go through a series of stress-strain hysteresis cycles with such rapidity that there is no time for the recovery of the permanent set given by the first landing shock; the hysteresis factor is thus reduced to some 20 to 30 per cent., and the rubber springing now acts

as a secondary or damped spring to absorb the smaller shocks due to taxi-ing.

Tests made upon rings of indiarubber, as used for aeroplane shock absorbers, in general give a lower tensile strength than similar tests upon straight strips of the same material: due to bending action, there being a difference in the stress between the inner and outer layers, and a change in the cross-section.

The rate of loading has only a secondary effect, provided that it is not too slow.

Temperature changes affect the results appreciably: an increase from 50° F. to 90° F. causes an average diminution in the tensile strength of about 10 per cent., with a 10 per cent. increase in the elongation, and 30 per cent. decrease in permanent set.

The results of some tests* upon rubber rings as used upon aeroplane undercarriages are shown in Fig. 125.

These rings measured 2 inches in mean diameter, by 2 inches wide by $\frac{5}{16}$ inch thick, and the average breaking load was 900 pounds per square inch, reckoned on the original area, with an average ultimate elongation of 265 per cent. of the initial length (that is, one-half of the mean perimeter). Specimens of the same rings which had been kept for one year in an office showed a tensile strength of 750 pounds per square inch, with an ultimate elongation of 240 per cent., showing that the " ageing " effect was appreciable.

The stress-strain curves shown in Fig. 125 are for three cycles of loading, the runs being continuous, without any time interval to get the exact permanent set; 3 minutes were allowed for the complete recovery from strain.

The hysteresis loss, or ratio of area of loop to the area under the ascending stress-curve, becomes smaller for each successive cycle, from 61 per cent. for the first cycle to 41 per cent. for the third cycle.

The corresponding values of the moduli of elasticity for

* " Notes on Aeroplane Shock Absorbers of Rubber," J. C. Hunsaker. *Aeronautics*, 11th Oct., 1916.

this grade of rubber were found to be 350, 340, 310, and 265 pounds per square inch respectively, for four specimens.

Tests made upon an actual aeroplane undercarriage bridge, consisting of 12 rubber rings, showed that the hysteresis losses for the first three cycles were 47, 26, and 28 per cent.

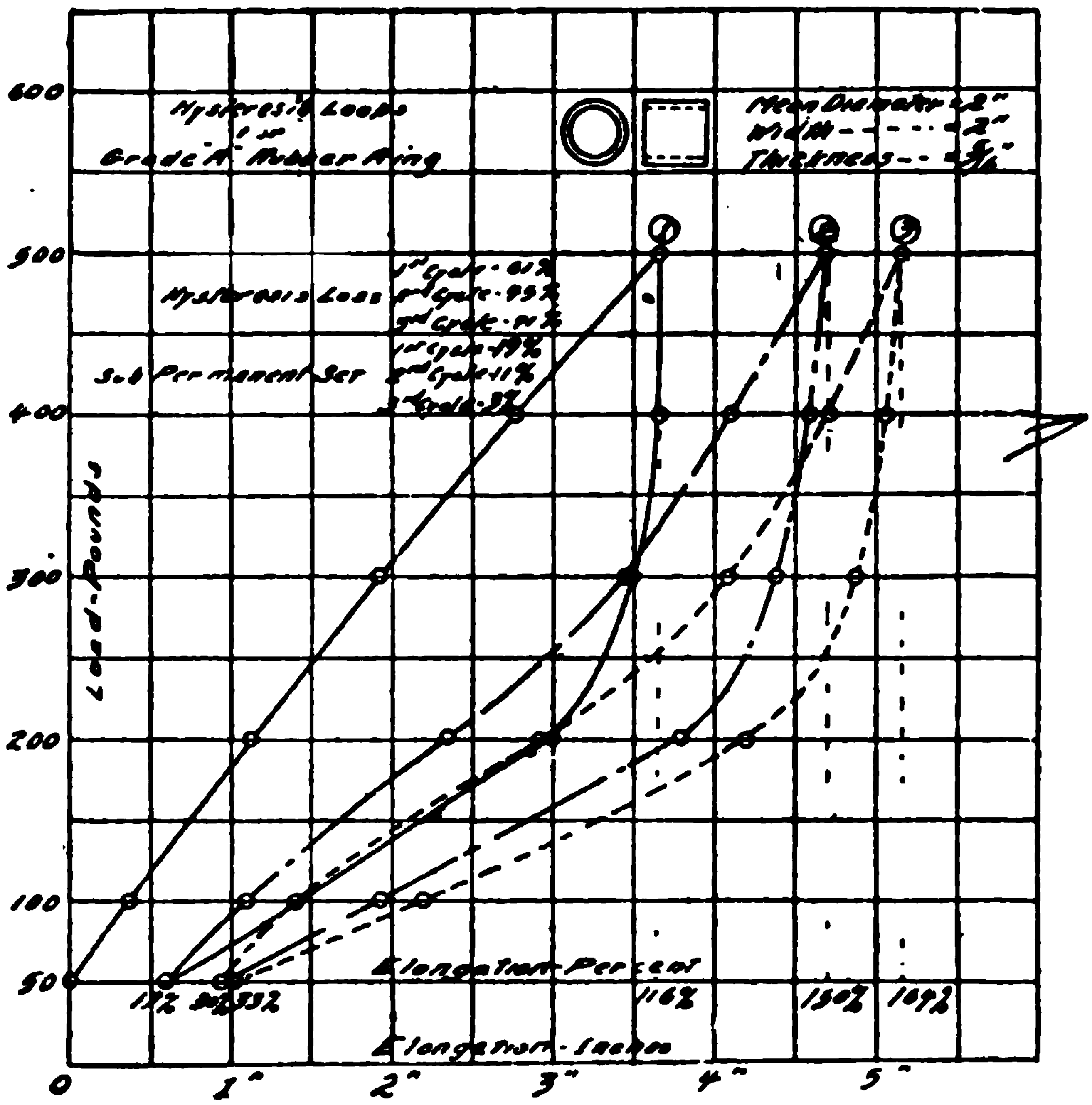



FIG. 125.

respectively, the modulus of elasticity of the rubber being 400 pounds per square inch.

As a result of the above-mentioned tests, it was suggested that the following specification was desirable for rubber intended for aeroplane undercarriages—

(1) COMPOSITION—

| | |
|---|---|
| Fine Para rubber .. .. | At least 45 per cent. |
| Total sulphur .. .. | Not over 3 per cent. |
| Free sulphur .. .. .. | Not over 1 per cent. |
| Acetone Extract .. .. | About 2·25 per cent. |

(2) Strength—

| | | |
|---|---|---|
| Tensile strength | .. | .. 1800 pounds per square inch |
| Elongation at rupture | | .. 1 to 6 |
| Permanent elongation | | .. 25 per cent. |

## Braided Elastic Cord.

Cotton braided elastic cord is much used for the springing of aeroplane undercarriages and tail skids. It consists of a large number of rectangular sectioned elastic filaments forming the central circular core, and an outer casing of diagonally opposed cotton threads, forming the casing.

In the case of the commonly employed $\frac{1}{2}$ inch diameter cable, there are from 150 to 200 rubber threads; this cable weighs about 2 ounces per foot run, and extends about 65 per cent. for a load of 65 pounds.

The advantages of braided rubber over plain rubber are that it has a greater hysteresis loss for a given weight, and an extension of about one-fifth of that of a similar cable but with the braiding removed; the braiding also acts as a protective covering.

The following results give the loads required to cause extensions of 200 per cent. for braided cables of different sizes.

TABLE CXXX.

Tests of Braided Rubber Shock Absorber.

| *Diameter in Inches.* | *Number of $\frac{1}{50}$ inch strands.* | *Load to cause double extension.* |
|---|---|---|
| $\frac{3}{8}$ | 95 | 80 |
| $\frac{1}{2}$ | 172 | 140 |
| $\frac{5}{8}$ | 266 | 220 |

For the same braided cable the results of strength tests show that the strength largely depends upon the initial tension put on the rubber cord and upon the angle at which the braiding is wound.

If the braiding is wound at too coarse an angle, a small extension of the cord has the effect of putting the larger

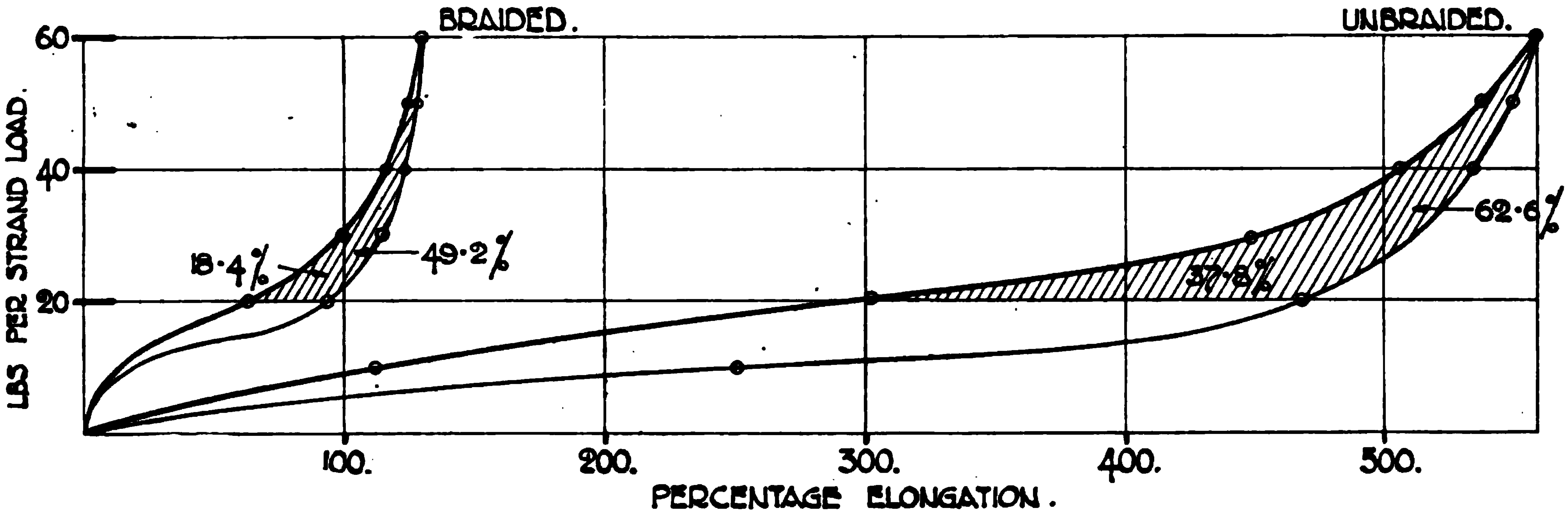



FIG. 126.—HYSTERESIS CURVES FOR BRAIDED AND UNBRAIDED RUBBER CORDS.

part of the load upon the braiding instead of upon the rubber, and the cotton soon breaks or disintegrates.

For the best results, the braiding should be put on at a fine angle, the initial tension depending upon the number of cords that are to be used for the machine, and its weight.

The tensile strength of braided elastic is not constant in a given coil, but varies at different parts of the coil, and for this reason it is considered better, in order to obtain uniform results, to employ a number of rings of braided cord.*

Tests made upon rings show that the energy absorbed in hysteresis is a larger percentage of the total energy than in the case of ordinary cord; in a ring it varies from 15 to 20 per cent.

The effect of repeated loading upon endless braided rubber is illustrated in Fig. 127 (*a*, *b*, and *c*), which show the results of tests made by Messrs. Luke Turner & Co.

In the first case (*a*), the static hysteresis curve is shown; in case (*b*) the results of a static loading test are shown, after the material has been given 500 repetitions of load to produce an extension of 66 per cent; in case (*c*), the static hysteresis curve is given after 10,000 repetitions of load, to produce an extension of 66 per cent.

The following are the results corresponding to the above three cases—

| | *Work done in stretching* 66%. | *Hysteresis.* | *Percentage Hysteresis.* |
|---|---|---|---|
| Initial test .. .. | 79·0 | 25·3 | 32·0 |
| After 500 repeated loadings | 62·5 | 15·0 | 24·0 |
| After 10,000 repeated loadings | 61·0 | 10·6 | 17·4 |

These results, and also the hysteresis curve areas in Fig. 127, show that the percentage hysteresis progressively falls off with repeated loadings.

Experiments carried out by Messrs. Boulton and Paul

* Endless braided elastic cords are manufactured by Messrs. Luke Turner & Co., Leicester.

A

B

LOAD IN LBS.

LOAD IN LBS.

STRAIN

INITIAL STATIC TEST.

STATIC TEST AFTER 500 REPETITIONS UNDER EXTENSION OF 66%

0

0 ·2 ·4 ·6 ·8 1·0

STRAIN

STATIC TEST AFTER 10,000 REPETITIONS UNDER EXTENSION OF 66%

FIG. 127.—TESTS UPON BRAIDED RUBBER RINGS.

showed that with a 10-inch ring of $\frac{5}{8}$ inch diameter, which was loaded gradually to a load of $\frac{1}{2}$-ton, the hysteresis, when the time taken to apply the load was $\frac{1}{2}$ minute, was less than one-fifth of that when the time taken was 4 minutes.

## British Standard Specification* for Rubber Shock Absorber Cord for Aircraft. (Extract.)

1 Construction.—The cord shall be made of multiple strands of cut rubber thread tightly encased in two coverings of cotton braid. The cord shall be as smooth and as uniform in diameter as possible.

2. Quality of the Rubber Thread.—The thread shall be of hard fine Para rubber vulcanized with the admixture of sulphur or other approved agent. All the cut strands shall be square in section.

3. Sizes of Cut Rubber Thread.—The count of the cut rubber thread shall be not larger in section than $\frac{1}{18}$ inch square nor smaller than $\frac{1}{30}$ inch square. Only one count of cut rubber thread shall be used in any one cord. A tolerance of plus or minus 5 per cent. will be permitted in the respective counts.

4. Test of Bare Rubber.—The degree of vulcanization shall be such that a strand 6 inches long shall extend to a length between 27 and 37 inches 60 seconds after the application of the load given in the following table. The extension of any of the threads in any one warp shall not differ by more than 5 inches.

| Counts. | Inch. $\frac{1}{18}$ | Inch. $\frac{1}{20}$ | Inch. $\frac{1}{22}$ | Inch. $\frac{1}{24}$ | Inch. $\frac{1}{26}$ | Inch. $\frac{1}{28}$ | Inch. $\frac{1}{30}$ |
|---|---|---|---|---|---|---|---|
| Load applied in grammes .. | 315 | 255 | 210 | 180 | 150 | 130 | 115 |

Sixty seconds after removal of the load a strand originally 6 inches long shall return to a length not exceeding $6\frac{3}{8}$ inches.

5. Method of Testing Cut Rubber Thread.—The cut rubber thread shall be held in suitable grips.† The top grip should be fixed vertically, and to the bottom grip, which should be a floating one, weights should be added to bring the combined weight to the required value, as given in the above table. The extension of each rubber thread shall be measured by means of two marks upon the thread, each mark at least $\frac{1}{2}$ inch distant from the jaws of the grips and 6 inches distant from each other when the rubber thread is in its normal condition. These marks may be indicated conveniently by tying white cotton on to the cut rubber thread. The load shall be applied gradually

* British Engineering Standards Association.

(*Note.*—The Association desires to call attention to the fact that this Specification is intended to include the technical provisions necessary for the supply of the material herein referred to, but does not purport to comprise all the necessary provisions of a contract.)

† Strong spring wooden clothes pegs faced with fine glass paper or rubber upon the gripping surfaces are suitable.

by supporting the weight in the hand and allowing it to sink slowly to the point where the rubber thread carries the entire weight. The temperature of the test room shall be between 60°F. and 70°F., at which temperature the rubber shall have been kept for at least 3 hours prior to the test.

6. Braiding.—Both the inner and the outer coverings shall be made of best American two-fold cotton yarn in the grey; the inside cover shall be of soft American cotton, and the outer cover of hard, polished glacé American cotton.

7. Sizes of Finished Cord.—The overall diameter, including the braid, shall be one of the following three sizes: ⅜ inch, ½ inch, or ⅝ inch. A tolerance of ± 10 per cent. shall be permitted on the overall diameter.

8. Number of Rubber Strands.—The standard sizes of cord shall be obtained by using a minimum number of rubber strands in accordance with the following table—

| *Size of cord.* | *Minimum number of strands of rubber.* | | | | | | |
|---|---|---|---|---|---|---|---|
| | Inch. $\frac{1}{18}$ | Inch. $\frac{1}{20}$ | Inch. $\frac{1}{22}$ | Inch. $\frac{1}{24}$ | Inch. $\frac{1}{26}$ | Inch. $\frac{1}{28}$ | Inch. $\frac{1}{30}$ |
| Inch. | | | | | | | |
| ⅜ | 77 | 95 | 114 | 136 | 160 | 186 | 213 |
| ½ | 139 | 172 | 208 | 247 | 290 | 336 | 386 |
| ⅝ | 215 | 266 | 322 | 383 | 450 | 522 | 600 |

9. Finished Cord.—The cord shall be made up whilst the bare rubber is under an initial strain calculated to give the following loads in the finished cord—

| *Size of cord.* | *Load in pounds to give* 10% *extension.* | *Load in pounds to give* 100% *extension.* | | *Load in pounds to give an extension of* 5% *beyond* 100%. |
|---|---|---|---|---|
| Inch. | Min. | Min. | Max. | Max. |
| ⅜ | 20 | 70 | 70 | 15 |
| ½ | 35 | 130 | 155 | 25 |
| ⅝ | 55 | 200 | 240 | 40 |

10. Tests upon Finished Cord.—Any coil of finished cord may be tested at four regions, selected indiscriminately throughout its length, and the average test results shall be in accordance with the loads and extensions set out in the table in Clause 9.

11. Method of Testing Finished Cord.—The temperature of the test room shall be between 60° F. and 70° F., at which temperature the cord shall have been kept for at least 3 hours prior to the test. The portion of cord to be tested shall be stretched three times to 100 per cent. extension in order that any "shrinkage" or "creeping" may take place before determining the test loads. Five inch lengths of cord shall be tested in a spring balance machine designed to give a uniform rate of stretch, and which is capable of testing the cord without cutting the coil. The complete extension—not including the hysteresis measurement—shall be completed in 90 seconds.

**Applications of Rubber.**

The principal applications of rubber, with which the present considerations are concerned, are in connexion with motor and aeroplane tyres, shock absorber rings or braided cord, petrol and oil-proof rubber hose, and water pipes.

For motor car and cycle covers, a medium grade of rubber is employed, reinforced upon the inner side with one, two, or more layers of strong rubber impregnated fabric, the beaded portions near the rims receiving special attention.

The sizes of these covers vary from 650 millimetres diameter by 65 millimetres section diameter up to about 950 millimetres by 150 millimetres or above, and the air pressures in the inner rubber tubes vary from 45 pounds per square inch in the smaller sizes up to 90 pounds per square inch in the larger sizes, as indicated in Table CXXXI.

TABLE CXXXI.

MOTOR CAR TYRE SIZES, WEIGHTS, AND PRESSURES.*

| *Section of tyre. Size in millimetres.* | *Maximum Weight which tyre can carry. Pounds.* | *Average weight carried. Pounds.* | *Pressure of air inflation. Pounds per sq. in.* |
|---|---|---|---|
| 65 | 550 | 330– 440<br>440– 550 | 46<br>60 |
| 75 | 550 | 330– 440<br>440– 550 | 42<br>56 |
| 85 | 660 | 440– 550<br>550– 660 | 42<br>56 |
| 90 | 880 | 550– 660<br>770– 880 | 42–50<br>60–65 |
| 105 | 990 | 660– 880<br>880– 990 | 42–60<br>70 |
| 120 | 1320 | 880–1100<br>1100–1320 | 42–60<br>70 |
| 130 | 1430 | 1100–1320<br>1320–1430 | 42–60<br>70 |
| 150 | 1600 | 1400–1500 | 80–90 |

(*Note.*—The pressures in front wheels should be about 7 pounds per square inch less than the above.)

* The Michelin Tyre Co.

For aeroplane use, the pneumatic covers must not only be as light as possible, but should be capable of receiving the side-shocks due to the machine landing with side-drift on.

Fig. 128 illustrates the Palmer aero tyre; it will be seen to be much lighter in construction than the motor cover, as the amount of wear is very small; but it is exceedingly strong in the lateral sense.

The ordinary beaded-edge car cover is not suitable for aeroplane undercarriages, as the lateral stress set up in landing in a side wind, or with drift on the machine, causes the "toe" of the tyre bead to lift, which allows the air tube to blow underneath and to burst, or else the tyre is pulled clean off the rim.

In the tyre illustrated, this difficulty is obviated by giving the wheel rim the particular shape shown, and by incorporating in the bead of the tyre steel staples, which give rigidity to the bead and prevent it from pulling out. The inner ends of these staples rest on the raised centre portion of the rim, whilst the outer portions project outwards to the edge of the bead, locking the latter in position in the rim.

The wheel itself is widely splayed, and is provided with plain phosphor bronze bearings, as shown in Fig. 129; each wheel is given about ⅛ inch side-play at the hub.

Small steel hooks are either vulcanized into the sides of the cover (in the larger sizes), or sewn on to the edge-tape of the cover, and the doped fabric discs or shields fitted for reducing the head-resistance of the wheels, are fastened into place upon these hooks, as shown in Figs. 130 and 131.

The cords employed in the motor covers are made from a number of fine cotton threads, coated with rubber and twisted. Six of these finer cords are then insulated in rubber and twisted together, the threads being passed through a die containing rubber solution under a pressure of about 200 pounds per square inch. Four, or six, of these composite cords are then twisted under even tension so as to form one cord, which is again impregnated with rubber and is then

FIG. 128.

FIG. 129.

flattened between rollers under an even tension, and afterwards allowed to dry for some days. It is then passed through a second flattening machine, which reduces it to an exact size, and to a flatter and thinner section ready to be built into the

SPRING HOOKS

FIG. 130.

FIG. 131.

tyre carcase. These flattened cords are next laid diagonally upon a metal mould or former, having the exact shape of the inner side of the tyre, in a special machine, after which a second layer of cords is placed diagonally, but in the opposite direction, with layers of rubber in between.

The thickness of the cords and the number of strands in them are selected to suit the particular size of cover.

The treads of the tyre are extruded in one smooth-surfaced piece of uncured rubber, and are worked carefully into place around the exterior of the casing. The cover is then ready for vulcanizing and is placed in a mould and subjected to the necessary curing, the tyre being made on the single curing process. This curing is done under fluid pressure applied from the inside of the carcase, the mould being bolted together solidly before the pressure is applied.

It is not possible to describe the process of tyre construction in any further detail, but the reader is referred for fuller particulars to the articles* mentioned in the footnotes.

The aeroplane tyres are made in a variety of sizes and sections varying from 300 millimetres by 60 millimetres up to 1750 millimetres by 300 millimetres, the latter tyres being used upon the largest types of machine. The air pressure employed in the inner tubes is about 50 pounds per square inch for practically all sizes.

### Tests of Aeroplane Tyres.

Fig. 132 illustrates the result of a test to destruction upon a Palmer aero tyre, in which two similar covers (750 by 125 millimetres) were placed on wheels, one at each end of an axle, which was loaded up to 2 tons (1 ton per wheel), and, in addition, a lateral pull of 2 tons was applied by means of a dynamometer.

The wheels themselves rested upon planes inclined at an angle of 1 in 4 ; the air pressure in the tubes was 65 pounds per square inch.

The tyres, under these conditions, yielded by distorting laterally or bulging at the lower portions near the inclined planes, the shape of the bulge being that shown in Fig. 133.

* "The Palmer Cord Tyre." *The Autocar*, 17th July, 1915, and 27th March, 1915 ; p. 341.

Fig. 132.—Destruction Test on Aero Tyre.

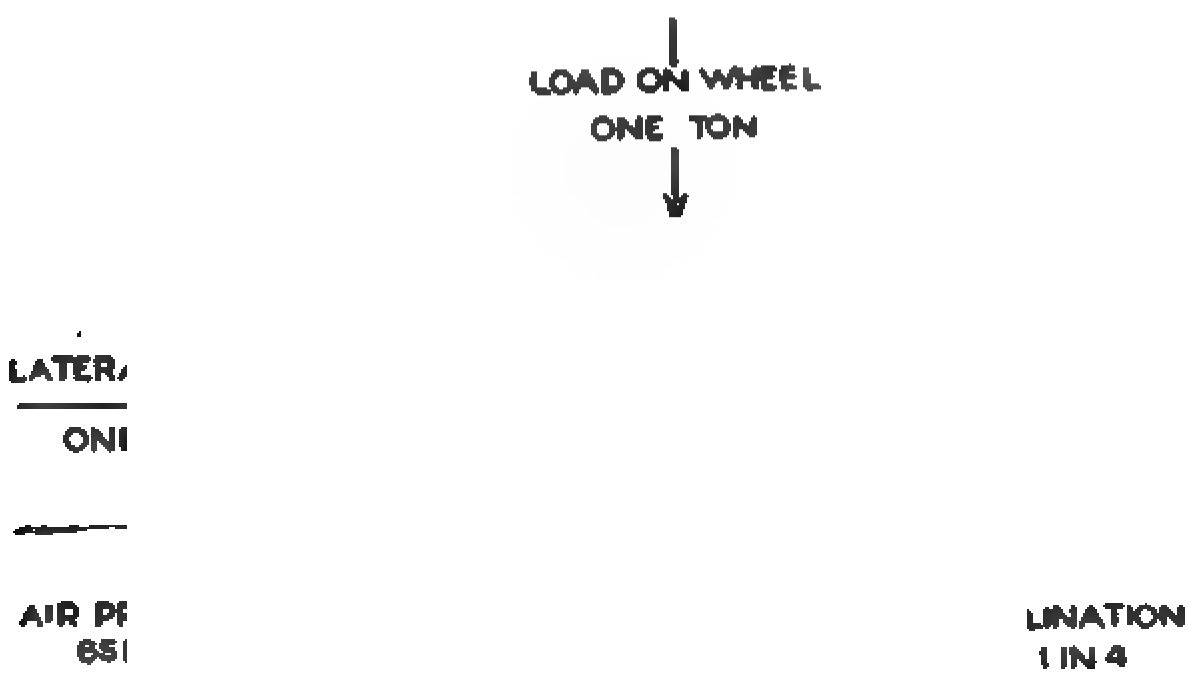



Fig. 133.

The beads of the cover, at the end of the test, were rigidly locked in position in the wheel rims; in the case of the ordinary car rim, the covers would have left the rims before the above loads were reached.

The following formula will be found to give the approximate permissible normal load on a Palmer aero tyre—

Normal load = Diameter (inches) × Tread (inches) × 12, pounds.

The weights and safe loads for the ordinary sizes of aeroplane wheels, tyres, and shields complete, are given in the following table, the safe loads being one-fifth of the maximum or destruction load.

TABLE CXXXII.

| *Size of tyre in millimetres.* | *Weight of complete wheel with tyre and shield.* | | *Safe load in pounds.* |
|---|---|---|---|
| | *Pounds.* | *Ounces.* | |
| 600 × 75 | 12 | 3 | 1000 |
| 700 × 75 | 14 | 14 | 1100 |
| 700 × 100 | 21 | 6 | 1600 |
| 750 × 125 | 23 | 8 | 1800 |
| 800 × 150 | 28 | 2 | 2200 |
| 900 × 200 | 55 | 0 | 4000 |
| 1100 × 220 | 81 | 0 | 5000 |
| 1250 × 250 | 114 | 0 | 6000 |
| 1500 × 300 | 145 | 0 | 8000 |
| 1750 × 300 | 194 | 0 | 9000 |

**Hysteresis of Aeroplane Tyres.**

When an aeroplane tyre (properly inflated on its wheel) is gradually loaded, the tread below the centre line compresses, the deflections increasing with the load. If, now, the load be gradually taken off, it will be found that at each value of the load the corresponding deflection is greater than before, the difference being due to a hysteresis effect; in other words, the tyre does not regain its original shape at each load.

If, now, the load deflection curves be plotted for increasing and decreasing loads, as shown in Fig. 134*, which represents the results of an actual test, the area between the loading and unloading curves will represent the energy lost, or dissipated in heat (due to internal friction, etc.). In the case of an aeroplane landing, part of the kinetic energy of the machine is absorbed or used up in virtue of the tyre hysteresis, and part by that of the shock-absorbing device and the framework of the machine.

From measurements of hysteresis curves similar to that shown in Fig. 134, it has been found that, under static loading and unloading conditions, about 8 per cent. of the total work is dissipated, or absorbed in the hysteresis effect.

Fig. 135 shows some typical load deflection curves for Palmer aero tyres; the unloading curves are not, however, given.

Aeroplane wheels are subjected, not so much to static, but to impact or bouncing loads, in practice, and it is under the latter conditions that their behaviour should, therefore, be examined.

If a loaded wheel and tyre of weight W pounds be dropped from a height $h$ feet, it will rebound to a height $h_1$ feet. If the depression of the tyre be called $d$ feet, then we have—

Initial energy (potential) of tyre $= W(h + d)$ foot-pounds
Final „ „ „ $= W(h_1 + d)$ „ „
Hysteresis energy, by difference $= W(h - h_1)$ „ „

or, expressed in terms of the original energy—

$$\text{Percentage hysteresis loss} = 100 \cdot \frac{h - h_1}{h + d}$$

The following results† were obtained from a 750 × 125 millimetres Palmer aero tyre, which was loaded to 150·5 pounds and bounced.

* Some useful data on aeroplane tyres and springing devices will be found in "Aircraft Undercarriages," J. D. North. *Aeron. Journ.*, Feb., 1920.

† Taken from the Paper above.

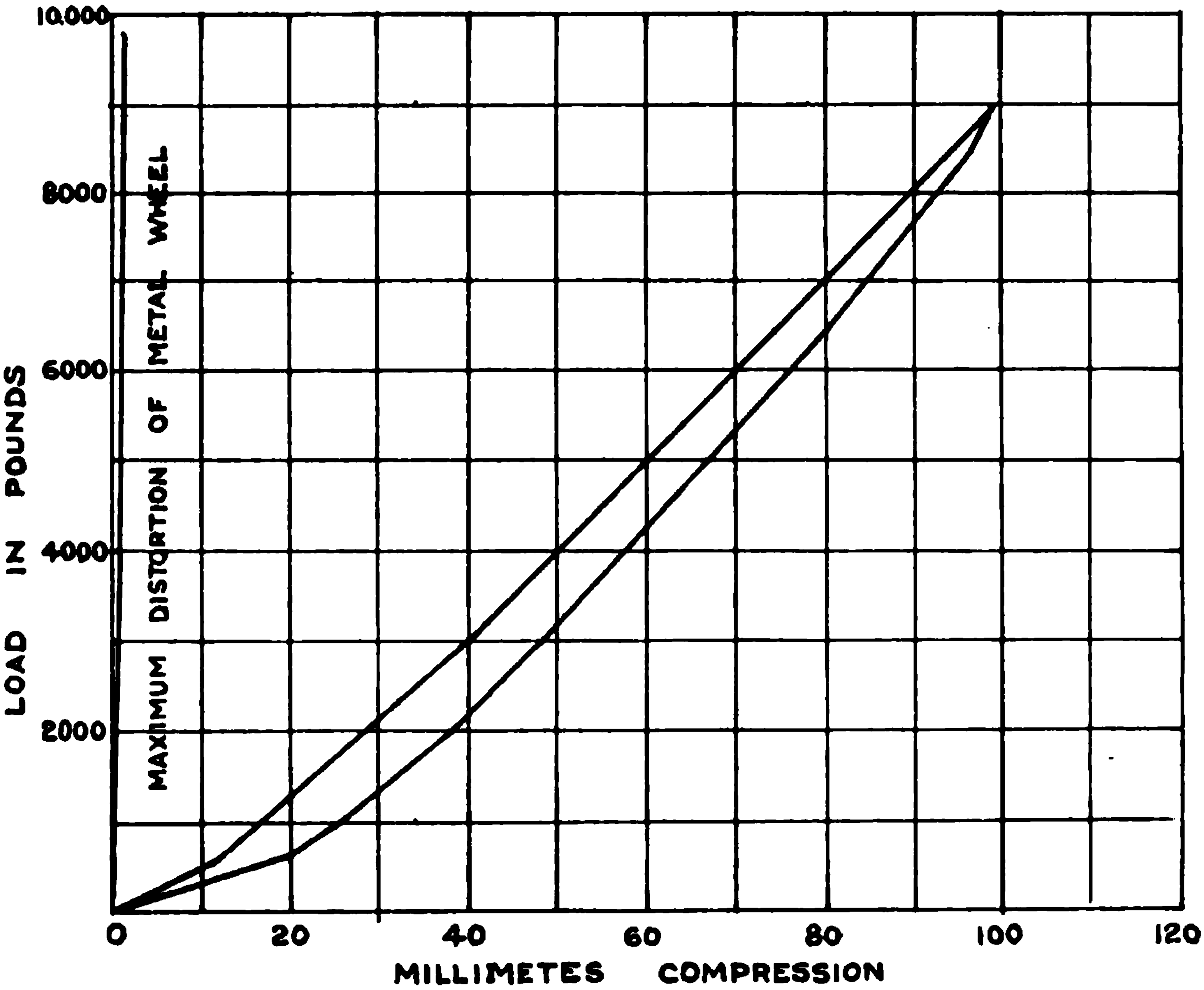



FIG. 134.—HYSTERESIS CURVE FOR COMPLETE WHEEL AND TYRE.

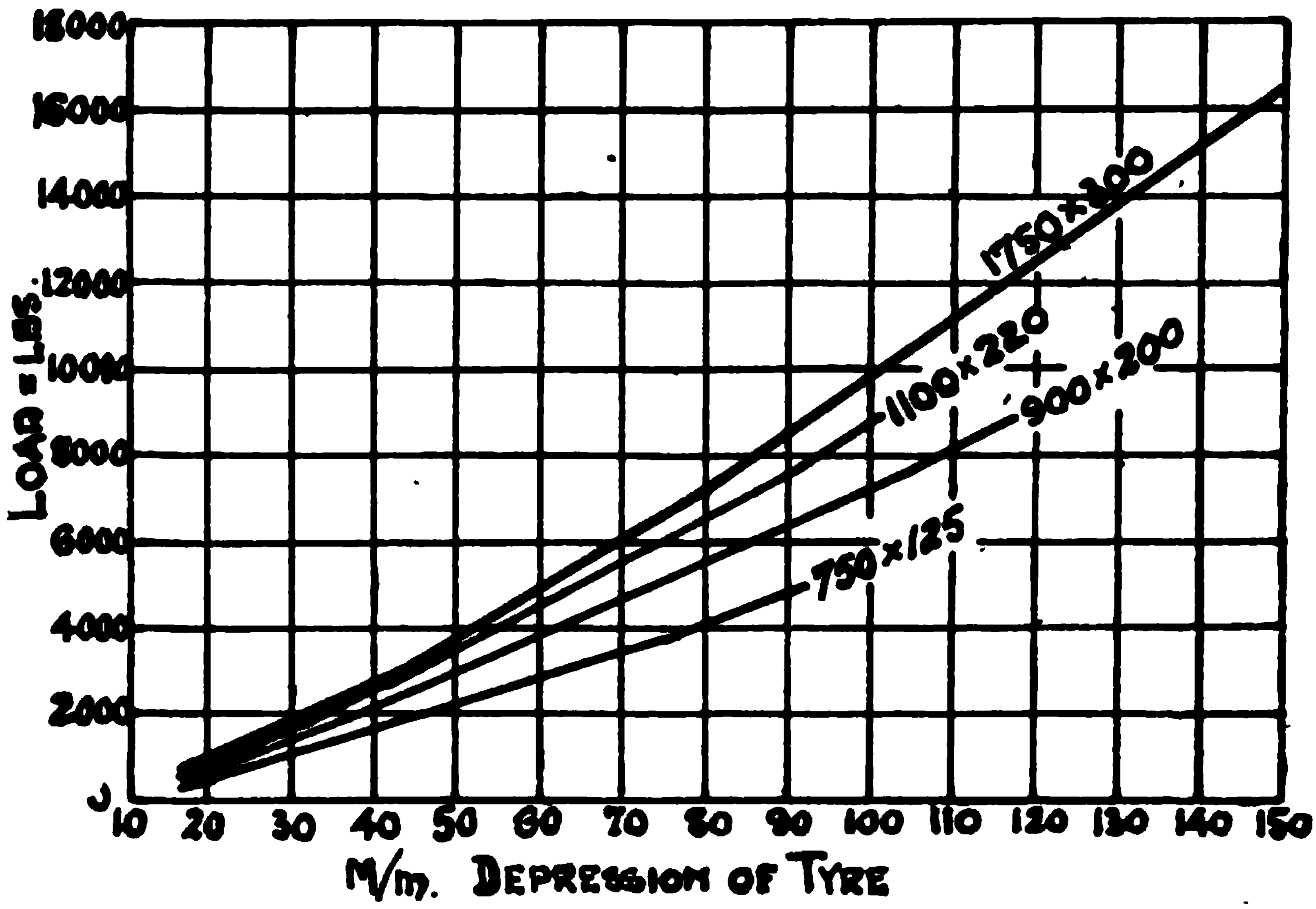



FIG. 135.

TABLE CXXXIII.

| *Height of drop, h feet.* | *Depression. d feet.* | *Energy taken up in foot pounds.* | *Energy given up on rebound in foot pounds* | *Energy dissipated in foot pounds.* | *Energy dissipated, per cent.* |
|---|---|---|---|---|---|
| 1 | 0·15 | 172·5 | 133·3 | 39·2 | 22·7 |
| 2 | 0·20 | 330·9 | 264·2 | 66·7 | 20·1 |
| 3 | 0·24 | 487·5 | 396·7 | 90·8 | 18·6 |
| 4 | 0·28 | 643·3 | 526·7 | 116·6 | 18·1 |
| 5 | 0·31 | 800·0 | 656·7 | 143·3 | 17·9 |
| 6 | 0·34 | 954·2 | 768·3 | 185·9 | 19·5 |

Before analyzing the above results, it will be interesting to examine the behaviour of the same wheel when subjected to static loads. The following were the results obtained in this case—

TABLE CXXXIV.

| *Depression, d feet.* | *Load in pounds.* | *Energy taken up in foot pounds.* | *Energy given up in foot pounds.* | *Energy dissipated in foot pounds.* | *Energy dissipated, per cent.* |
|---|---|---|---|---|---|
| 0·15 | 2110 | 125 | — | — | — |
| 0·20 | 3100 | 250 | 230·8 | 19·2 | 7·7 |
| 0·24 | 3790 | 385 | 355·8 | 29·2 | 7·6 |
| 0·28 | 4500 | 550 | 507·5 | 42·5 | 7·7 |
| 0·31 | 5250 | 724·2 | 669·2 | 55·0 | 7·6 |
| 0·34 | 5800 | 904·2 | 830·8 | 73·4 | 8·1 |

Comparing the results of the static and dynamic tests above given, it will be at once observed that more energy is absorbed, for a given tyre depression, in the latter case, and a much higher percentage is dissipated, namely, about three times that in the former case. The energy absorbed in the case of the static load is approximately about 70 per cent. of the dynamic load energy.

Fig. 136 illustrates, graphically, the results given in the above table.

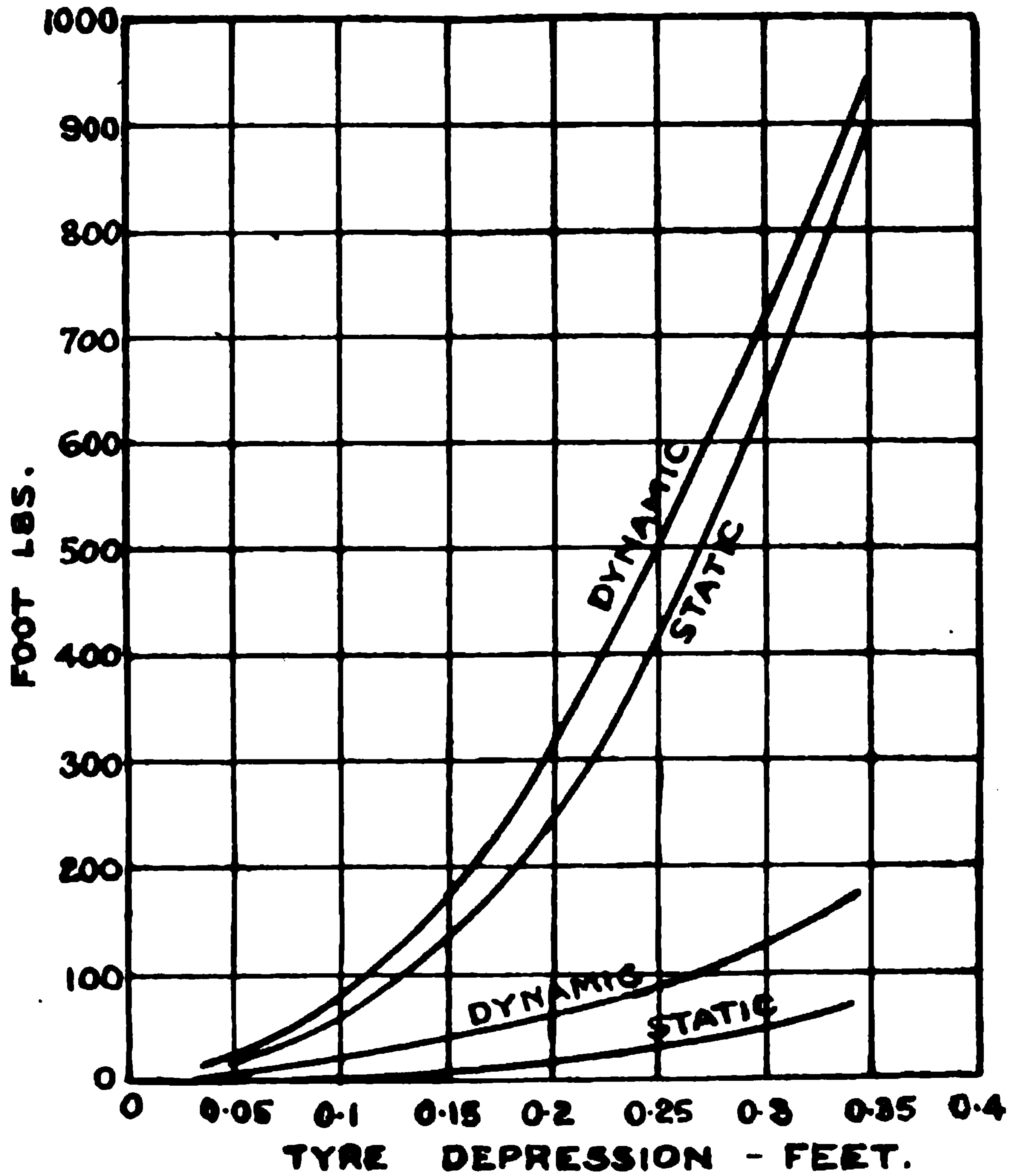



FIG. 136.

## INTERNATIONAL AIRCRAFT SPECIFICATIONS FOR RUBBER HOSE.

*Rubber Hose for Use with Gasoline*
*(Aeronautic).*

### TYPE 2.—Cotton Inside Reinforced with Wire.

#### PART I.—TECHNICAL.

(*a*) DESCRIPTION.

1. *Construction.*—The gasoline hose must consist of rubber and cotton constructed in the following manner, and the quality of the finished hose must be uniformly good throughout.

2. *Inner Tube.*—The inner tube shall consist of a canvas tube supported by a helix of oil tempered steel wire of not less than ·020 inch diameter, spaced not less than five turns per inch. The rubber tube shall be placed between this inner cotton tube and the cotton plies specified below.

3. *Cotton Plies.*—The cotton shall consist of either braided or canvas plies and shall comply with the following table. The inner cotton tube shall not be considered one of the plies specified.

| Internal diameter hose | Up to and including $\frac{5}{8}$ inch. | $\frac{11}{16}$ inch to $1\frac{1}{2}$ inch | Greater than $1\frac{1}{2}$ inch |
|---|---|---|---|
| No. of plies | Not less than two. | Not less than three. | Not less than four. |

4. *Outer Cover.*—An outer cover of rubber of the same quality as that used for the inner tube, and of good workmanship and finish.

5. *Dimension Limit.*—The internal diameter of the hose must not vary more than plus or minus 3 per cent. of the internal diameter stated on the order.

6. *Length of Hose.*—The contractor, when quoting or when acknowledging an order for this class of hose. must state the lengths in which it can be supplied. The hose should be supplied in the maximum lengths possible.

(*b*)—PHYSICAL PROPERTIES.

7. *Flexibility.*—By " Flexibility " is meant capacity to bend without kinking.

8. When hose of internal diameter ($y$) is bent around a cylinder having a diameter equal to $x$ times the external diameter of the hose, as shown in the following table, the external diameter of the hose must not increase or diminish by more than 10 per cent.

| Internal Diameter of Hose ($y$) | $x$ |
|---|---|
| Less than $\frac{1}{2}$ inch = .. .. .. | 8 |
| $\frac{1}{2}$ inch to $\frac{3}{4}$ inch .. .. .. .. | 12 |
| $\frac{13}{16}$ inch to $1\frac{1}{2}$ inch .. .. .. .. | 14 |
| Above $1\frac{1}{2}$ inch .. .. .. .. | 16 |

9. The hose, after having been filled with gasoline for 2 hours, must withstand a minimum internal hydraulic pressure of $P$ pounds per square inch, depending upon the internal diameter ($D$) of the hose without showing defects.

| (*d*)—Internal Diameter in Inches. | *Minimum pressure in pounds per square inch* ($P$) |
|---|---|
| Up to $\frac{1}{2}$ inclusive .. .. .. | .. 160 |
| $\frac{9}{16}$ to 1 inclusive .. .. .. | .. 140 |
| $1\frac{1}{16}$ to $1\frac{1}{2}$ inclusive .. .. .. | .. 120 |
| $1\frac{9}{16}$ to 2 inclusive .. .. .. | .. 100 |
| Above 2 inclusive .. .. .. | .. 80 |

(*c*)—CHEMICAL PROPERTIES.

10. *Rubber.*—No organic matter other than Para or Plantation rubber shall be used in the preparation of this hose.

11. The percentage of rubber shall not be less than 32 per cent.

12. The amount of free sulphur in either the tube or the cover shall not exceed 1 per cent.

12. The amount of free sulphur in either the tube or the cover shall not exceed 1 per cent.

13. *Dry Heat Test.*—A 3 inch piece of the hose, after having been placed in an air oven at 132° C. for 2 hours, must show, when cool, no tendency to crack, and must not be tacky.

14. *Permeability to Gasoline Test.*—(The specific gravity of the gasoline used in this test should be between 0·710 and 0·725 at 60° F. ;

65 per cent. of it must distil at over 100° C. from a distillation flask when the bulb of the thermometer is just below the side tube). A 14 inch length of the hose is held vertically and plugged at the bottom. The upper end is fitted with a glass tube about 18 inches long. The hose so arranged is filled with gasoline to a head of 12 inches above the top of the acting length of the hose. The acting length of the rubber hose is 12 inches. The upper end of the glass tube is loosely closed with a cork.

15. During the first 24 hours the level of the gasoline will fall comparatively rapidly. The loss of gasoline is made good by frequent additions from a known volume of gasoline, care being taken that the level of the gasoline in the glass tube does not fall at any time by more than 3 inches. The test is to last for 72 hours, and the loss of gasoline during the third 24 hours must not exceed 100 cubic centimetres per square foot of the original internal surface of the hose.

16. *Immersion in Gasoline.*—A 3 inch piece of the hose is boiled for 1 hour (using a reflox condenser) in gasoline similar to that used for the permeability test. The gasoline is allowed to cool down. Twenty-four hours later the test piece is removed from the gasoline and examined without delay, as follows—

17. The internal diameter at the point of greatest constriction is measured by means of rod gauges. From this measurement the area of the bore is calculated. It must not differ from the original by more than 25 per cent.

18. The test piece is then cut longitudinally into halves, and the adhesion between rubber and cotton carefully examined. The adhesion must be of such a character that the rubber can only be stripped from the cotton by hand with difficulty.

19. *Immersion in Oil.*—A 3 inch piece of the hose is immersed in "Vacuum A" or other oil (approved by Purchasing Office) at a temperature of 100° C. for 8 hours. and for a further period of 24 hours at ordinary temperature. The oil is then wiped from the surface of the hose. The decrease of internal diameter shall be less than 10 per cent.

20. The flexibility and elasticity of the rubber must not be diminished, and there must be no tendency of the rubber to separate from the cotton.

## PART II.—INSPECTION.

21. *Test Pieces.*—The purchaser will decide where the tests are to be carried out. All test specimens are to be cut in the presence of the Inspector, and they are to be marked as he may direct.

22. For the purpose of testing, a representative sample will be cut from each 1000 feet of hose or fraction thereof, and the tests will proceed in accordance with the Purchasing Office's instructions.

23. *Rejections.*—If any sample fails to comply with any of the above tests, the hose represented thereby will be rejected.

24. *Marking.*—Accepted and rejected material must be marked as directed by the Inspector.

CHAPTER XI

# PAINTS AND PAINTING

PAINTS are employed to protect metal, wooden, and other surfaces against atmospheric influences, and also for decorative purposes.

The nature of the paint employed is largely governed by the type of surface and the material to be covered; for example, parts that are situated outdoors require a different kind of paint and method of painting to parts which remain under cover or indoors. It is usual to employ enamels, varnishes, and polishes for inside work, and oil, bituminous, and creosote paints for outside work. The general rule is to employ the more expensive and better quality paints for objects of worth, and for general indoor decorative work, and the cheaper paints for general outdoor work.

Paint is a mechanical mixture of a vehicle or medium, and a pigment, together with the addition of suitable materials, known as *driers*, for facilitating the drying of the painted surface.

Paint is a mixture or suspension of the pigment and driers in the vehicle, rather than a chemical combination, and for this reason paints must be well ground or mixed before use, otherwise the more liquid portions remain at the top and the pigment and solid particles at the bottom.

Paints differ from varnishes in that the latter are actual solutions of resins or gums in oil or spirit, whereas the former are mechanical mixtures, which owe their drying and hardening effects to the oxidation of the vehicle into a hard elastic skin or covering.

## INGREDIENTS OF PAINTS

The essential ingredients of paints are—

(*a*) The vehicle, medium, or binder, which consists of

linseed oil or an inferior substitute, in the case of *oil paints*, spirits and varnish* in the case of *enamels*.

(*b*) A pigment, or pigments, which are inert solid particles or powders which give no chemical reactions with the vehicle or dryers, and which serve to give both a " body " and the required colour to the paint.

The pigment also serves to thicken the oil or vehicle, and to give to the dry paint a certain degree of resistance to abrasion ; during the hardening of the oil, minute holes are frequently formed, which would render the film porous but for the pigment particles. It is therefore important to thoroughly grind or pulverize the pigment before mixing with the other constituents.

The principal pigments used are white lead (carbonate or oxy-sulphate), red lead (peroxide), white zinc (oxide), iron oxides, graphite, lamp-black, bone-black, chrome-yellow, chrome-green, ultramarine, Prussian blue, and others.

(*c*) A drier, or japan, the function of which is to accelerate the drying and solidification of the paint.

Driers are chiefly lead and manganese compounds soluble in oil, and they act as carriers of oxygen.

There are several kinds of driers in use, but the best contain litharge or sugar of lead, the former being employed for paints of dark or medium colours, and the latter for the lighter colours.

The following† are typical examples of driers—

(1) DRIER WITH LITHARGE—

| | |
|---|---|
| Litharge .. .. .. .. | 1⅛ pounds |
| Whiting .. .. .. | 5 ,, |
| Barytes .. .. .. .. | 3 ,, |
| Sugar of lead .. .. .. | 1⅛ ,, |
| Sulphate of zinc .. .. | 2¼ ,, |
| White lead .. .. .. | 1⅛ ,, |
| Refined linseed oil .. .. | ½ gallon |

(2) DRIER WITH SUGAR OF LEAD—

| | |
|---|---|
| Sugar of lead .. .. .. | 9 pounds |
| White lead .. .. .. | 2¼ ,, |
| Whiting .. .. .. | 1½ ,, |
| Boiled linseed oil .. .. | 1 quart |

The ingredients are mixed and well ground together.

* See p. 454.

† Spon's " Workshop Recipes."

(3) DRIER WITHOUT OIL.—

| | | | |
|---|---|---|---|
| Oxide of zinc | 3 parts by weight | | |
| Borate of manganese | 4 | ,, | ,, |
| Barytes | 11 | ,, | ,, |

These are ground very fine and well mixed. The powder is sprinkled into the paint for drying purposes.

(4)

| | | | |
|---|---|---|---|
| Resin | 7 parts by weight | | |
| Litharge | 5 | ,, | ,, |
| Resinate or borate of manganese | 1 | ,, | ,, |
| Boiled linseed oil | 12 | ,, | ,, |
| Turpentine | 48 | ,, | ,, |

The resin is melted first, and the oil then added. The mixture is heated up to receive the other ingredients.

Other driers for zinc-white and similar paints consist of cobalt and manganese benzoates, cobalt and manganese borates, manganese-oxide, and resinates of cobalt and manganese. Varnish paints, or enamels, require no driers as a rule.

When the vehicle or medium is spread out upon a surface, it should, when dry, form a thin colourless hard, elastic film, which is not liable to decay or deteriorate under atmospheric influcnces. Boiled linseed oil and its substitutes form the most commonly used oil paint vehicles, but for artists' work poppy and ground-nut oils are often used.

**Linseed Oil.**

The properties of this commonly employed vehicle are considered on p. 498.

**Pigments.**

Of the white pigments, white lead has the greatest body or opacity, three coats of this pigment being equal to about five of white zinc, but white lead coatings are more liable to peel.

White zinc is more brilliant and permanent, and it is usual to mix the two pigments for standard white and light coloured paints.

The coloured pigments are the coloured salts of various metals. The anhydrous oxides of iron are brown and purple-brown, whilst the hydrated oxides are yellowish-red to reddish-yellow. Most iron oxides are mixtures of both varieties, and frequently contain clay and manganese besides ; they are commonly employed in cheap paints and give durable results. Many of the yellow coloured pigments are chromium salts ; for example, chrome-yellow, orange-chrome, and lemon-chrome. Green pigments often contain arsenic salts, and are considered dangerous for this reason.

The following are the principal pigment colours and materials—

| *Colour.* | *Pigment Material.* |
|---|---|
| White .. .. .. | White lead, zinc white, barium sulphate |
| Red .. .. .. | Red lead |
| Blue .. .. | Ultramarine and Prussian blue |
| Yellow.. .. .. | Chrome yellow (lead chromate) |
| Green .. .. .. | Chrome green (chromium sesquioxide) and arsenic salts |
| Brown, red-brown, etc. | Siennas, umbers, etc. |
| Black .. .. .. | Lamp-black, carbon |

## White Lead.

This is a hydrated carbonate of lead, $2PbCO_3$, $Pb(HO)_2$, and is an opaque, heavy, white pigment widely used in paints. It is usually supplied in the paste form ground in oil, ready for mixing into paint. White lead is not so durable as some of the other coloured pigments, and is liable to deteriorate or decompose in exposed situations and under the influence of the sun and sea air ; for this reason it lasts longer in houses and in towns than when used in exposed seashore places. It is, however, considered to be the most satisfactory of the white pigments.

## Zinc White.

This is an oxide of zinc (ZnO) obtained by volatilizing zinc in an ordinary atmosphere. It is lighter, harder, and more

durable than white lead, but it requires more oil to mix it into paint form, and has cnly about one-half to three-fifths of the covering power of white lead. The two compounds are frequently mixed together in paints.

**Red Lead.** ($Pb_3O_4$).

This is a red powdered oxide of lead; it frequently contains litharge (PbO), which causes the linseed oil to lose some of its hardening power.

Pure red lead is quite inert in linseed oil, and will remain in a neutral mechanical suspension for very long periods; it should contain at least from 94 to 98 per cent. of $Pb_3O_4$.

Red lead paints are much used for protecting iron surfaces, such as ships' plates and boilers, from corrosion; boiled linseed oil is generally employed for the purpose, and thc paint has marked adhering qualities. This paint is also used as a priming paint for metals and wood.

**Iron Oxide Pigments.**

These consist of ordinary and hydrated oxides, aud the natural oxides such as those derived from haematites are characterized by their dull brown and brownish-red colours. Iron or ferruginous earths form the constituents of the umbers, ochres, and siennas, used as paint pigments. When these ores or earths are roasted before grinding into powder they are known as "burnt" pigments; for example, "burnt sienna," "burnt umber," etc.

Iron oxide paints are very durable and adherent, and are much used for protecting metal surfaces, and for wood.

**Carbon Pigments.**

These comprise lamp-black, bone-black, ivory-black, and graphite, and are chemically inert substances, or allotropic forms of carbon. For metal protection, graphite paints are frequently employed, but for wood covering paints, carbon substances are only employed as pigments or colouring materials.

Lamp-black is a voluminous but light powder produced by the combustion of rich mixtures of hydrocarbons with air. It is a neutral and very durable pigment for black paints, but it requires more oil than other pigments and takes much longer to dry.

## FILLERS

Before the first coat of paint or enamel is applied to any surface it is necessary for satisfactory results to fill up all holes, cracks, and fissures in the surface, so that a smooth uniform surface may be obtained.

The most commonly employed filling is ordinary putty, but the best fillings consist of whiting and linseed oil made into a paste.

For finer work, red lead and linseed oil are sometimes used.

In the case of hard, porous woods, starch and boiled linseed oil mixed with a little turpentine may be used. The filling is coloured with pigment to suit the paint employed.

### Propeller Fillers.

Fillers for propeller work are now obtainable in the ready-mixed, coloured or transparent paste form, and are applied with a brush ; a period of from 24 to 48 hours is allowed for the filling material to dry, after which the surface is rubbed down with fine sand-paper. For very fine work, a second and thinner coat is given, using the same materials, but with less oil and more japan and turpentine.

When this coat is dry and hard, the first coat of paint may be applied.

Linseed oil, itself, is a good filler for woods that are to be painted ; this sinks into the wood and fills up the pores so that it not only forms a smooth base for receiving the paint coatings, but is also a hard, durable skin.

For fine-grained hard woods the oil may be thinned with turpentine, in order to give it better penetration properties. It is frequently advantageous to introduce a little priming or coloured pigment into the oil to help fill up the pores in

the wood and to distinguish the "filled" parts from the natural untreated wood.

A good filling material should not shrink appreciably on drying, and for this reason the paste variety of fillers are rather better than the liquid type.

Many fillers consist of silica, litharge, whiting, resins, powdered bark, and other powdered solids mixed with oils or spirits.

**Varnish Fillers.**

Woods that require to be finally varnished or polished are usually filled with a transparent filler, which may be either of varnish or linseed oil.

The priming varnish used for the purpose should be fairly thin, so that it penetrates the pores and openings of the wood.

The method of varnish finishing aircraft propellers is described on p. 472.

The following are the constituents of one or two typical fillers*—

(*a*) Ordinary Putty—

| | |
|---|---|
| Whiting .. .. .. | 14 pounds |
| Raw linseed oil.. .. .. | 1 quart |

The whiting should be well dried and crushed before mixing with the oil to a dough or paste.

(*b*) *Quick-Setting Putty*—

| | |
|---|---|
| Whiting .. .. .. | 14 pounds |
| Litharge .. .. .. .. | 2 ,, |
| Driers .. .. .. .. | 8 ounces |
| Linseed oil (raw) .. .. | 1 quart |

(*c*) Filler for Fine Cabinet Work.—A fine filling compound is made by mixing powdered plaster of Paris with warm glue of thin consistency. This substance sets fairly quickly and should be used soon after making.

(*d*) Liquid Filler—

| | |
|---|---|
| China clay .. .. .. | 3 pounds |
| Turpentine .. .. .. | 3 pints |
| Resin varnish .. .. .. | 6 ,, |
| Raw linseed oil.. .. .. | $2\frac{1}{2}$ ,, |

* Spon's "Workshop Recipes."

A drier may be added to facilitate the drying process. It is not possible to deal more fully with the subject of paints here, but for fuller information the reader is referred to the works given in the footnotes.*

## VARNISHES †

Varnishes are made by dissolving gums or resins in oils or spirits; when oil is the solvent the term "oil varnish" is employed, and when a spirit, such as alcohol, spirits of wine, or methylated spirits is used, it is termed a "spirit varnish." Turpentine varnish contains turpentine as the solvent. In general, oil varnishes require a longer period in which to dry, but give harder, more elastic, and more durable coverings than the quicker drying spirit varnishes.

Correctly speaking, the term "gum" is applied to vegetable gums, such as gum arabic, which are soluble in water, and the term "resin" to those resins or vegetable substances which dissolve in oil or spirit.

A gum which dissolves in water is not in general suitable for varnishes, as it will not withstand weather influences.

The resins employed in varnishes may be roughly grouped under three headings, namely—

(*a*) Fossil resins, such as amber and fossil kauri.

(*b*) Semi-fossil resins.

(*c*) Modern resins, such as dammar, mastic, and pine resins.

The resins which are used for oil varnishes include the kauri resins, etc., whilst those used for spirit varnishes include shellac, sandarac, dammar, and mastic.

The more expensive, brilliant, and permanent varnishes

* "Painters' Colours, Oils, and Varnishes," G. H. Hurst. (Griffin & Co.).
"The Painters' Laboratory Guide," G. H. Hurst. (Griffin & Co.)
"The Chemistry of Paints," Friend. (Longmans, Green & Co., London.)
"White Lead and Zinc Paints," Petit. (Scott, Greenwood & Sons, London.)
"Lead and Zinc Pigments," Holley. (Wiley & Sons.)

† Also see Chap. XII, "The Protection of Metal Surfaces," Vol. I, "Aircraft and Automobile Materials."

are those embodying amber, fossil kauri, and Zanzibar resins, and these are much used for protecting paintings, for piano work, and high-class cabinet work, etc.; they are sometimes employed in the better varieties of spar and coach varnishes.

**Amber.**

Amber is a hard, yellow, or yellowish-brown substance found in geological deposits, and is a fossilized resin or gum derived from a large number of varieties of trees. It is often found upon sea-shores, amongst pebbles, and in alluvial deposits, but the commercial material is found in the Baltic field. Amber has a specific gravity of about 1·08.

The better specimens of amber are used for ornaments, beads, tobacco pipes, and in jewellery, whilst the darker grades and chippings are used in varnishes.

**Copal.**

This is a name applied to a large variety of modern resins of tropical origin, which form the ingredients of spirit or copal varnishes.

**Kauri.**

The modern kauri gums are obtained from the kauri pine of Australia, whilst the fossil kauri resins are excavated from the known areas upon which the trees have thrived. This latter substance dissolves in linseed oil and forms an excellent varnish of the more expensive class.

**Shellac.**

This is derived from modern resin deposits or exudations, known as *lac*, found upon the branches of certain tropical trees.

The stick or seed lac is purified, melted, and then spread out upon flat surfaces to cool, when it forms thin flakes or sheets, known as " shellac " (shell-lac).

Shellac is soluble in alcohol and is much used in quick-drying varnishes for resinous and softwoods in general. It is

partially soluble in water. It is usually employed for varnishing cheap woodwork articles, and for protecting wood surfaces against atmospheric influences. Shellac is also used in lacquers for metals such as brass and steel.

**Sandarac.**

This is a modern resin obtained from trees growing in North Africa and in Australasia. It is used in pale spirit varnishes for light-coloured articles and woods, for piano work, etc.

**Dammar.**

This is a soft white resin derived from tropical trees, which is used in white transparent varnishes and in white enamels. It is soluble in turpentine, and forms one of the turpentine varnishes; it requires the addition, however, of other hardening ingredients.

**Zanzibar.**

This resin forms one of the ingredients of the best varnishes, owing to the hard, brilliant, and durable nature of the film formed upon drying. It is frequently mixed with other resins in varnishes, such as "spar varnish," coach and piano varnishes.

**Rosin.**

This is a cheap modern resin, derived from pine-gums, by distillation from the crude turpentine. It is sometimes known as pine-rosin or colophony. Rosin forms the principal ingredient of most cheap varnishes, and when applied to a surface gives a yellowish-white film of a polished, glassy appearance. It is not durable, but darkens in colour and cracks; the addition of oil to the varnish is an improvement from this latter standpoint.

**Mastic.**

This is a modern resin from trees which grow in Mediterranean countries. It is clear and brittle, but becomes

white and plastic when masticated. It is soluble in spirits such as alcohols, and is used for hard and white varnishes, often with other gums and resins.

**Lacquers.**

These are hard varnishes employed upon brass, copper, steel, and other metals in order to retain their original colours and polishes. Lacquer is so called because it contains either seed-lac or shellac. The shellac employed is usually bleached so that it becomes white, and gives a transparent, colourless solution; the bleached variety is not so good as the natural shellac, however, nor as durable.

In lacquering, the metal surface must be well cleaned, freed from grease, and highly polished. The metal is then heated to from 80° to 100° C. in a non-oxidizing atmosphere, and the lacquer is applied thinly with a camel-hair brush, evenly, in one direction. Small articles should be heated more than large articles, owing to the cooling effect of the lacquer.

The solution of lacquer may be coloured for certain metals if desired.

Lacquering is much employed for scientific instrument brass, and similar work, for electrical screws, terminals, switches, etc., aircraft and automobile instruments, and numerous other purposes.

**Typical Varnish Compositions.**

(*a*) HARD SPIRIT VARNISH—

| | |
|---|---|
| Gum sandarac .. .. .. | 8 ounces |
| Turpentine .. .. .. | 3 ,, |
| Rectified spirits of wine .. | 1½ pints |

(*b*) COPAL VARNISH—

| | |
|---|---|
| African gum copal .. .. | 1 pound |
| Clarified oil .. .. .. | 2 pints |
| Turpentine .. .. .. | 3½ ,, |

The copal is first melted and then the oil is added. The mixture is boiled for 4 or 5 hours until quite stringy, when it is mixed with the turpentine.

(*c*) Hard White Spirit Varnish—

| | |
|---|---|
| Gum sandarac .. .. .. | 3½ pounds |
| Spirits of wine .. .. .. | 1 gallon |
| Pale turpentine .. .. | 1 pint |

The sandarac is dissolved in the spirits of wine and the turpentine is afterwards added and well shaken.

(*d*) White Varnish—

| | |
|---|---|
| Gum copal .. .. .. | 1 pound |
| Camphor .. .. .. | 2 ounces |
| Alcohol .. .. .. .. | 4 pints |
| Gum mastic .. .. .. | 4 ounces |
| Venice turpentine .. .. | 2 ,, |

The camphor and copal are dissolved in the alcohol, and mastic and turpentine are then added. The mixture is well strained. This varnish is very white, and is hard, brilliant, and durable.

(*e*) Black Varnish—

| | |
|---|---|
| Egyptian asphaltum .. .. | 3 pounds |
| Shellac .. .. .. .. | ½ pound |
| Turpentine .. .. .. | 1 gallon |

The asphaltum is first melted and the latter ingredients then added.

(*f*) Turpentine Varnish—

| | |
|---|---|
| Resin .. .. .. .. | 1 pound |
| Turpentine .. .. .. | 1 quart |

The resin is dissolved in the warm turpentine.

**Lacquers.**

(1) For Brass—

| | |
|---|---|
| Shellac .. .. .. .. | 1 pound |
| Sandarac .. .. .. | 4 ounces |
| Annatto .. .. .. .. | 4 ,, |
| Dragon's blood resin .. .. | ½ ounce |
| Spirits of wine .. .. .. | 2 gallons |

(2)

| | |
|---|---|
| Shellac .. .. .. .. | 1 pound |
| Spirits of wine .. .. .. | 2 gallons |

(1) FOR IRON AND STEEL—

| | |
|---|---|
| Amber | 12 ounces |
| Asphaltum | 2 ,, |
| Resin | 2 ,, |
| Turpentine | 12 ,, |
| Drying oil | 6 ,, |

(2)

| | |
|---|---|
| Asphaltum | 3 pounds |
| Shellac | $\frac{1}{2}$ pound |
| Turpentine | 1 gallon |

(3) TRANSPARENT VARNISH FOR IRON AND STEEL NICKLE-PLATING ETC.—

| | |
|---|---|
| Mastic (clear) | 10 ounces |
| Camphor | 5 ,, |
| Sandarac | 15 ,, |
| Gum elemi | 5 ,, |
| Alcohol | Sufficient for a clear liquid |

This lacquer may be applied cold to the metal.

## SPECIFICATIONS FOR AIRCRAFT VARNISH.

A Committee of the Society of Automotive Engineers recommended the following specifications for aeroplane spar varnishes—

COMPOSITIONS AND GENERAL PROPERTIES.—The material shall be the best long oil varnish suitable for application on wood, "doped" linen or cotton, and metal, and resistant to light, air, and water. The manufacturer is given the greatest latitude in the selection of raw materials and process of manufacture in order to produce a product of the highest quality.

PHYSICAL CHARACTERISTICS.—The material shall comply with the following requirements—

1. It shall be clear and transparent.

2. Its colour shall be no darker than a standard colour solution made by dissolving 6 grammes of pure powdered potassium bichromate in 100 cubic centimetres of pure concentrated sulphuric acid (specific gravity 1·84). Gentle heat may be used, if necessary, to secure a perfect solution of the bichromate. The colour comparison will be made by placing the varnish and the standard colour solution in clear, thin walled glass tubes of the same diameter, 1·5 to 2 centimetres ($\frac{5}{8}$ to $\frac{13}{16}$ inch) to a depth of at least 2·5 centimetres (1 inch) and comparing the colours by looking through the tubes across the column of the liquid by transmitted light.

3. It shall not flash below 35° C. (95° F.) in an open tester.

4. The varnish shall be flamed on one side of a 10 × 15 centimetre (approximately 4 × 6 inch) panel of bright tin. The panels shall be approximately 0·3 to 0·4 millimetre (0·0125 to 0·0158 inch) thick (90 to 100 pounds weight of base metal per standard box of 112 sheet 14 × 20 inches, No. 30 to No. 28 U.S. Standard plate gauge), and shall be cleaned thoroughly with benzol. When the panel is held in a vertical position and maintained at a temperature of 21° C. to 32° C. (70° to

90° F.), the varnish shall set to touch at a point not less than 2·5 centimetres (1 inch) from the side or top edges of the film, in not more than 5 hours, and shall dry hard in not more than 24 hours to a clear, hard, glossy film. The panel will then be allowed to dry for a further period of not less than 5 days, and with the varnished side on the outside, will then be bent double, rapidly, over a rod 3 millimetres (⅛ inch) in diameter. The varnish film shall show no cracking or flaking at the point of bending.

5. The varnish will be applied to a basswood panel which has been filled with one coat of lamp-black in oil thinned with turpentine and drier, and allowed to dry for not less than 10 days before applying the varnish. It shall have suitable body to give proper brushing, flowing, and covering properties. The first coat of varnish will be allowed to dry 48 hours, then lightly sand-papered, a second coat applied, and allowed to dry 72 hours. The panel will then be inclined at an angle of 45° and a gentle stream of cold tap water allowed to flow down the middle of the panel for 18 hours. After wiping off with a chamois skin any deposits due to tap water, the varnish shall show no whitening, dulling, or other defects. A small stream of boiling water will then be allowed to flow down another portion of the panel for 20 minutes. The water will be siphoned through a small glass tube directly from a container in which it is boiling on to the surface of the panel in such a manner that there will be no appreciable lowering of the temperature of the water before it touches the varnish film. The syphon delivery tube will be in a plane nearly parallel to the plane of the panel, so that the impact of the water will not tend to break the film. The varnish shall show no appreciable whitening and no more than a very slight dulling, or other indications of marked deterioration, either when observed immediately after removing from the water or after drying for 2 hours.

(*Note.*—In general, results comparable to those given by the above method may be obtained by flowing one coat of varnish on duplicate panels of bright tin thoroughly cleaned with benzol, allowing to dry 48 hours, and then immersing one of the panels in distilled water at room temperature for 18 hours and the other panel in boiling distilled water for 15 minutes. But the test on wood should be made in all cases where there is any doubt regarding the resistance of the varnish to water.)

6. The varnish will be applied in three coats to two unfilled panels of maple wood not less than 14 × 45 × 2 centimetres (5½ × 18 × 3¼ inches), allowing 3 days for the drying of each coat. The first coat, after drying indoors for three days, will be sand-papered lightly with No. 00 sandpaper before the application of the next coat. The second and third coats will not be sand-papered or rubbed, and the duplicate panels will be exposed out of doors 45° to the vertical, facing south, three days after the application of the finishing coat. The backs and edges of the panels will also be varnished with the same sample, but for these surfaces the details of the method of application as given need not be adhered to, and the effects of exposure will not be considered. On this test the varnish shall show satisfactory durability and weather resistant properties. In cases where the award of a contract cannot be delayed for the results of the exposure test, award may be made on the basis of the other requirements ; but a varnish of any specific brand which does not show up satisfactorily on an exposure test may be omitted from consideration in future awards, and a preliminary submittal of samples for making exposure tests may be called for.

7. The varnish shall be flamed on one side of a piece of terne plate 10 × 15 centimetres (4 × 6 inches), which has been previously thoroughly cleaned with benzol. The coating must extend entirely

across the width of the plate and for at least 14 centimetres (4½ inches) of the length. The plate shall then be held in a vertical position for 6 hours at room temperature (21° C. to 32° C.) (70° to 90° F.). It shall then be placed in an oven at a temperature not less than 135° C. (275° F.), or more than 149° C. (300° F.), for 17 hours. It will then be removed from the oven, kept at a temperature between 21° C. (70° F.) and 32° C. (90° F.) for not less than 6 nor more than 24 hours. The panel with the varnished side on the outside will then be rapidly bent double over a rod 30 millimetres (⅛ inch) diameter at a point not less than 5 centimetres. (2 inches) or more than 7·5 centimetres (3 inches) from the bottom of the plate. The varnish film shall show no cracking or flaking at the point of bending.

## APPLICATION OF PAINT

The wood or other surface to be painted should be quite dry and free from grease. Many cases of improperly seasoned timbers occur, in which the paint rapidly blisters and cracks, due to the expansion of the imprisoned moisture in the form of water vapour.

The usual method is to thoroughly dry the wood, or to burn off the old paint with a blow-lamp.

The first coat of paint applied to any new surface is termed the "priming" coat, and a paint of special composition is generally employed.

Priming coats serve to fill the exposed pores of the wood or metal, and accelerate the drying of the second coats; they dry quickly themselves and give a smoother finish to subsequent coats.

Priming paints usually consist of red lead and linseed oil. The following is the composition of a typical priming paint for general work—

| | |
|---|---|
| White lead .. .. .. | 4 pounds |
| Red lead .. .. .. | 2½ ounces |
| Driers .. .. .. .. | 1¼ „ |
| Raw linseed oil.. .. .. | 2 pints |

For ordinary constructional and building work, two or three coats of paint are usually given, and each coat takes from 1 to 3 days to dry properly. The drying of a paint depends upon the atmospheric temperature, the air circulation, and the nature of the paint.

For quick drying, a warm dry atmosphere is required, and

the air should be in constant motion over the surface that has been painted; a freshly painted surface may require several days, or even weeks, to dry in a wet and cold atmosphere, whereas only a few hours will suffice at high summer heats.

As the drying of paint depends chiefly upon the oxidation of the vehicle or medium, it is essential that a good supply of fresh air be maintained to supply the necessary oxygen. The effect of moisture in the case of enamels and varnish-paints is considered to be beneficial, as it appears to facilitate the formation of a hard elastic surface.

Paint should be applied thinly; a thick coat not only takes longer to dry but often remains spongy underneath the outer surface. Two hard, thin coats are much better than one coat of the same thickness.

Paint may be thinned down with linseed oil or turpentine. Linseed oil, when used as a diluent, gives rather better results than turpentine; the latter liquid causes the paint to dry with a dull surface, and the film is not so elastic or durable.

When painting objects requiring a smooth, highly polished finish, the successive coats of paint are rubbed down with powdered pumice and water, using a soft rag or sponge, and the last coat of paint is mixed with varnish so that it dries glossy. Several varnish coats are then applied, each being rubbed down before the next is applied. Coach and motor body-work is finished in this way.

It is very important to allow each coat of paint to thoroughly dry before the next is applied, otherwise cracks will appear on the finished surface. Similarly with varnish-finished surfaces the turpentine in the varnish has a marked action upon the oil contained in the underlying coat of paint, and if the latter is not thoroughly dry, that is to say, properly oxidized, the turpentine will attack it, and will soften the surface of the paint so that the varnish will shrink and crack in warm weather.

## COVERING POWER OF PAINT, ETC.

The covering power of any paint will depend upon its composition, the nature of the material painted, the condition of the surface, and the rate of drying. Thick paints of treacle-like consistency will only cover a relatively small area, whilst very thin paints will cover large areas but will require several coats.

Timber or metal which has been well filled and given a priming coat or two will require only a minimum of paint for a given area ; on the other hand, freshly planed or rough-cut timber will absorb a considerable quantity of paint.

First coats of paint require much oil in their composition, in order to thoroughly soak into the material ; on a previously coated surface more turpentine is required in order to make the paint soak into the work.

As an approximate estimate for the covering power of a good paint upon a fairly smooth wooden surface, it may be stated that a gallon of paint will cover about 200 to 300 square feet, and for smooth metal surfaces from 300 to 400 square feet. For open grained wood a gallon will cover only about 200 square feet, and for fine grained hardwood 300 to 400 square feet. The second coat in either case will cover about 350 to 500 square feet.

Thin bituminous paints,* when applied to clean metal surfaces, will cover from 750 to 1000 square feet per gallon.

For ordinary building work and general painting, about 5 pounds of putty and 2½ pounds of white lead will be required for stopping purposes.

The following table† shows the composition and quantities of the different coats of white paint required to cover 100 square yards of newly worked pine.

* Such as "Bowranite," see Ch. 12, Vol. I.
† "Paints and Painting," Spon.

## TABLE CXXXV.

### Composition and Quantity of Paint for 100 Square Yards of Pine Surface.

| | Red Lead. | White Lead. | Raw Linseed Oil. | Boiled Linseed Oil. | Turpentine | Driers | Remarks. |
|---|---|---|---|---|---|---|---|
| | *Lbs.* | *Lbs.* | *Pints.* | *Pints.* | *Pints.* | *Lbs.* | |
| **Inside Work** 4 coats not flatted | | | | | | | Occasionally more red lead is used, and less driers. |
| Priming .. | ½ | 16 | 6 | — | — | ½ | *Sometimes just enough red lead to give a flesh-coloured tint is used. |
| 2nd coat .. | —* | 15 | 3½ | — | 1½ | ½ | |
| 3rd coat .. | — | 13 | 2½ | — | 1½ | ½ | |
| 4th coat .. | — | 13 | 2½ | — | 1½ | ½ | |
| **Inside Work.** 4 coats and flatting | | | | | | | |
| Priming .. | 1½ | 16 | 6 | — | ½ | 1–8 | |
| 2nd coat .. | — | 12 | 4 | — | 1½ | 1–10 | |
| 3rd coat .. | — | 12 | 4 | — | — | 1–10 | |
| 4th coat .. | — | 12 | 4 | — | — | 1–10 | |
| Flatting .. | — | 9 | — | — | 3½ | 1–10 | |
| **Outside Work.** 4 coats not flatted | | | | | | | For coloured paints nearly all boiled oil may be used. |
| Priming .. | 2 | 18½ | 2 | 2 | — | 1–8 | |
| 2nd coat .. | — | 15 | 2 | 2 | ½ | 1–10 | |
| 3rd coat .. | — | 15 | 2 | 2 | ½ | 1–10 | |
| 4th coat .. | — | 15 | 3 | 2½ | — | 1–10 | For pure white, use a large proportion of raw linseed oil. |

## TABLE CXXXVI.

### Covering Power of Paint Upon Different Surfaces.

| Nature of surface. | Area of surface covered by 1 gallon of paint. | |
|---|---|---|
| | *Superficial feet.* | *Superficial yards.* |
| Stone or brick .. .. | 225–270 | 25–30 |
| Composition .. .. | 360–450 | 40–50 |
| Wood, Open grain.. .. | 350–450 | 40–50 |
| ,, Hard close grain .. | 450–650 | 50–72 |
| Well-painted surface or iron | 700–750 | 78–85 |

## CARRIAGE AND MOTOR BODY PAINTING

There are three principal methods of painting car and carriage bodies which are employed, namely : (1) The brush or hand method ; (2) the compressed air or spraying method ;

and (3) the method of dipping, or immersion ; these will each be briefly considered in the order named.

**The Brush Method.**

All of the earlier examples of road and railway carriages were painted and finished by hand, and the results obtained were undoubtedly very satisfactory from both the appearance and durability standpoints. The methods employed, however, involved the expenditure of a considerable amount of time and skilled labour.

It was not an uncommon thing for from 16 to 24 coats of varnish to be applied to the painted structure, each coat being rubbed down with pumice and water before the next coat was applied; it is estimated that the process occupied an aggregate of about 700 hours.

The ordinary method of coach painting carried out in small works consists in first smoothing down with glass-paper all rough places in the wood or metal, and in filling up all cracks, holes, and other cavities with a suitable " filler." The surface is then given a priming coat of paint, which forms the foundation for the subsequent coats, and which should be carefully chosen and applied. The priming paint should be of good material, mixed carefully from good red lead and oil ; it should be applied lightly so that, in the case of wood, it penetrates well. It is sometimes recommended* that two priming coats of a red-lead base paint should be given to the car before it is puttied.

The putty recommended is made from ground lead and japan, stiffened up with dry lead, with a pigment to give the same colour as the finished one ; the filling should dry quite hard in 18 hours.

After the car has been given two primary coats and filled, the next coats should be made to dry flat and hard ; for all ordinary work two coats of the paint are sufficient, each coat being sand-papered. For high-class work, a heavy coat

* McKeon, " Master Car Painters' Association," U.S.A.

is given so as to thoroughly fill the grain, and before being set, is scraped with a steel scraper; for this coat, which is called "filling," one-half ground lead and one-half mineral is used. When the filling is thoroughly hard, it is sand-papered and another coat of paint of ordinary consistency is then given and sand-papered.

The next procedure is to give the car its finishing colour, the surface now being in a suitable condition to receive this. The finishing coloured paint should contain just enough driers to cause it to set in about 18 to 24 hours. It is essential that the under-coats should not contain too much oil, otherwise, owing to their elasticity, they tend to cause cracking in the outer coats.

It is better to use good boiled oil, or partly boiled oil which has been well strained, and ground powdered pigments for colouring, in preference to oil-ground or prepared colours, as the latter deteriorate with age before being used.

After the finishing coat of paint has been well set, the car is ready for varnishing. Three coats of varnish are necessary for the best work. The first coat should be a hard-drying varnish put on the flat colour, the composition of the varnish being such that it will dry in from 3 to 5 days in a dustless room at about 60° to 65° F.

The striping, lining, and transfer work is usually done over the first varnish coat, or sometimes upon the finishing coat of paint. The car is, in some cases, thoroughly washed after the first coat of varnish, and is then given the second coat of medium varnish; this coat is allowed to dry in from 6 to 8 days, and is then lightly rubbed down with curled hair or fine pumice powder and water, using a soft sponge or chamois leather.

The finishing coat of varnish is then given, and this should take from 7 to 10 days in which to dry hard. It should then be washed with clean cold water and a soft brush, and is then ready for use. This process occupies, in all, from 4 to 8 weeks or more.

The amount of varnish used per 100 square feet of carriage or car-body surface, for the three coats, varies from $\frac{1}{2}$ to $\frac{3}{4}$ gallon.

A cheaper and more common method of painting motor car bodies is to smooth down and fill all cavities, first with a filler of the same colour as the final coat, and to give two or three priming coats, followed by sand-papering. The finishing colour is next applied, which dries with a matt surface; and a coat of half varnish and half finishing colour applied, or a varnish-paint or enamel, so that a semi-glossy coating is obtained.

This is then rubbed down with pumice and water, and one or two coats of finishing varnish are given.

The whole process, in this case, takes from 2 to 4 weeks.

Metal parts, such as some types of chassis frames, motor cycle and cycle frames, tubular members, etc., are usually enamelled with a slow-drying varnish-paint, after having been well cleaned and polished, and then dried in a stoving oven, which "bakes" or "sets" the enamel with a hard, highly polished surface.

## The Spraying Method of Painting.*

In this process the paint is sprayed on to the surface to be coated by means of compressed air, through a suitable design of nozzle.

The spraying method is very useful for articles of an intricate shape, where the hand-brush method could not be properly carried out, and where the method of dipping is not suitable; for cavities and awkward corners the spraying method is the more preferable.

Sometimes the part is given a priming coat by dipping, and a final coat of varnish by spraying; it is generally agreed that the spraying method gives a better finish.

Spraying can also be used in cases where the whole article is not required to be painted, as in the case of the body

* See also p. 386

of a motor car, which, if plunged into a dipping bath would receive paint upon both the inside and outside, which is not always desirable.

The spraying process should be carried out in a proper room or cabinet fitted with an air exhaust, to prevent the operator from inhaling the fumes of the paint or varnish itself.

It is, of course, important to employ paints and varnishes of the correct degree of viscosity or consistency, in order that the proper spraying effect may be obtained; these can be obtained from firms who have made a special study of spraying paints. The compressed air for spraying, which is delivered at a pressure of from 15 to 25 pounds per square inch, should be quite free from oil or grit.

By employing stencils or masks, it is readily possible to do decorative and lining work with spraying apparatus. Parts, such as number plates, nickelled fittings, handles, etc., which do not require painting upon a car body, or other article, may be protected either by applying a coat of vaseline or by means of a suitable thin metal mask.

It has been estimated* that in the case of railway carriage painting by the spraying method, the cost of application per unit for a given number of square feet is about 40 per cent. of the cost of the hand-brush method; more paint is also given per coating by the latter method. A given surface which would require 10 gallons of paint for one coat by the brush would require approximately 7 gallons by the spray method.

**Spray Painting Automobile Bodies.**

A method of painting motor car bodies which is widely employed in America† consists in forcing the paint, japan, or varnish through a flexible tube, and discharging the liquid continuously through a flat nozzle. A trough-like tank is

* "Painting by Dipping, Spraying, and Other Mechanical Means," A. Seymour Jennings. *Journ. Roy. Soc. Arts*, 7th April, 1916.

† Known as the "Aeron Process."

provided, into which the superfluous liquid flows, but sufficient sticks to the surface to give a good, thick, and durable coating. In order to prevent the inside of the body from being splashed with paint, a brush is first used to apply it to the top edges, and then the nozzle is passed rapidly over the surface on to which it discharges the paint. The superfluous material which flows into the tank passes through a filter and is used again, being continuously added to that in use. The body is allowed to drip for some minutes and is then placed in a drying oven, which is specially designed so as to exclude moisture. The varnish coat dries in rather over 4 hours, and may then be rubbed down lightly, either with fine steel, wool, hair, or powdered pumice, when it is ready to receive another coat.

Another method for finishing an aluminium body consists in first washing the body in petrol, which is brush-applied for the purpose; this is wiped off and allowed to dry. A coat of oxide of iron priming and linseed oil is then given by means of an ordinary sprayer or air brush, and the body is then placed in an oven for 3 hours; the temperature of the oven is kept at about 115° F.

The body is then ready to receive a coat of coach putty, which is applied by hand, the object being to obtain a good smooth surface. This is allowed to dry in the air for 12 hours. Next, a coating of one-half white lead and one-half rough stuff is sprayed on, and the body is stove dried at 115° F. for 3 hours. The next process is to spray on four coats of rough stuff and to stove each at the same heat for 2 hours each. Next, a coat of rubbing rough stuff is applied by hand; this is air-dried and then rubbed down with pumice. Some additional puttying is then usually required. The body is now in a condition to receive the first coat of colour, which is sprayed on; this coating is allowed to dry in the air for 6 hours. The "Aeron," or spraying machine, is then employed to put on three coats of colour and varnish or enamel, the first two being stoved at 120° F. for 4 hours, and the last at 125° F. for 4½ hours. A coat of rubbing varnish is next applied,

which is afterwards rubbed down with powdered pumice and water. The body is then washed down with clean cold water and allowed to dry, when it is ready to receive the finishing coat of varnish. This last coat is usually applied by hand, using flat varnish brushes, and an excellent finish is obtained.

Although the above process necessitates a rather large number of coats, it gives very brilliant and durable results, and occupies considerably less time and labour than the older coach-painting methods.

Another rapid and inexpensive method of painting motor car bodies, but which does not, however, give such good results, consists in discharging the japan through a flexible tube connected with an overhead tank, through a wide nozzle, the discharge being controlled by means of a thumb lever and spring. The motor body is placed on a bogey inside a trough-shaped tank on three sides and with a solid iron sheet on the fourth side. On pressing the thumb lever the japan pours out of the nozzle on to the work, and by rapid manipulation the whole body can be coated in a space of about 2 minutes. A large quantity of the liquid naturally passes into the trough-shaped tank; this passes through a gauze filter into a tank below, whence it is pumped into the overhead tank ready for use again. After allowing a few minutes for the superfluous japan to run off, the body on the bogey is run into the drying stove, where it is left for a few hours to dry. It is afterwards rubbed down and given a second coat.

**Painting Aluminium Automobile Bodies.**

The surface of aluminium requires proper preparation before it can be painted, as the ordinary paints will not adhere very well to the polished fine-grained surface of sheet aluminium, as used in body work.

The surface should be first cleaned with petrol or benzine to remove all grease, and should then be rubbed, in a series of small rotary motions, with emery cloth, in order to obtain the necessary matt surface for the paint to adhere.

Alternatively, the surface may be frosted by the method described on p. 140; sheets and mouldings are now supplied* in the matt condition for painting.

Paint can now be applied direct to the surface, and will "take" quite satisfactorily, but it is better to give a preliminary coat of gold size or some similar coating. In some cases a transparent priming coating of raw linseed oil, three parts, and quick-drying varnish, one part, is given.

Another priming consists of keg white lead mixed with one part of raw linseed oil to three parts of turpentine. White lead mixtures should not be applied directly to the surface of aluminium, as there is a certain action resulting in a powdering of the lead, which prevents proper adhesion of the paint.

The next coat should consist of nine parts dry white lead, one part lamp-black thinned with six parts turpentine, one part raw linseed oil, and a few drops of coach japan.

In the majority of cases two coats of coloured paint and three coats of varnish are sufficient, but for very fine results several coats of varnish should be given, each coat being rubbed down with powdered pumice and water before the next is applied.

Less paint is required than in the case of wooden bodies, owing to the non-absorbent nature of the surface.

**Painting by Dipping.**

In this method, the article to be painted is lowered into a suitably shaped dipping tank, which is usually metal-lined, and is then taken out and placed upon an inclined metal floor to allow the superfluous paint to run and drip off for a few minutes. The excess of paint is then led through a filtering gauze back into the main tank.

The liquid in the dipping tank, which may be either paint, enamel, japan, or varnish, should be kept in a state of agitation by means of a circulating pump, or paddles, and provided with means for regulating or stopping the circulation.

* The British Aluminium Co., Ltd., London.

This method is somewhat widely employed for painting and varnishing articles such as farm and military waggons, agricultural machinery, bedsteads, mangles, domestic ware, piano cases, etc.

The paints employed are usually sufficiently hard to receive a second coat within from 4 to 6 hours. In one method there are two tanks, one at each end of a long room, with rails between; the waggons to be painted are dipped at one end and proceed very slowly towards the other tank, and are just dry when they reach same. After dipping in this tank they are slowly returned to the first tank for another coating. The dipping process uses slightly more liquid than the hand-brush method, and, with special precautions, uniform results may be readily obtained.

## METHODS OF FINISHING AIRCRAFT PROPELLERS.*

The earliest examples of wooden air-screws were finished in almost the same manner as a high-class cab or car body, with a large number of successive coats of varnish, each coat being rubbed down before the next was applied. These air-screws certainly withstood vibration and atmospheric influences, as regards their polish, but the amount of labour involved was prohibitive from the quantity production standpoint. Later air-screws were French-polished, but this method involved a considerable amount of time, namely, from 6 to 9 hours for a two-bladed air-screw (continuous time); moreover, the results obtained by this method of finishing have been shown to be unsatisfactory under atmospheric and flying conditions.

Modern air-screws are now invariably finished by varnishing. The exposed portion of the wood is first given a coat of transparent wood filler, which is manufactured in semi-liquid form for the purpose. It is then given two or three coats of priming varnish; each coat is rubbed down before the next is applied. Next, a coat of undercoating varnish is given,

* See also "Moisture Resistant Finishes for Airplane Woods." Report No. 85, U.S. National Advisory Committee for Aeronautics, 1920.

and this is rubbed down with powdered pumice and water, using a felt pad or soft rag. Finally, a coat of finishing varnish is given, and this is allowed from 2 to 4 days in which to set. The result of this process is to give a hard, high-polished, elastic, and durable surface.

The I.A.S.B. specification* stipulates that propellers shall be finished by the application of one coat of filler, two coats of priming varnish, and three coats of spar varnish. Each coat should be allowed a sufficient time to dry before the application of the next coat.

**Fabric Covering.**

The tips of propellers, and occasionally the greater part of the surfaces, are usually covered with fabric for strengthening purposes. The fabric is immersed in boiling water in order to remove the dressing which would otherwise be detrimental to the glue, and when dry the fabric is applied to the blade in the glue room, which is maintained at 70° to 100° F.

The surfaces of the blades are scraped and toothed, but are not usually sand-papered. The glue is applied to both the fabric and the blade surface, and the two are pressed together with wooden rollers, which squeeze out the surplus glue ; a warm iron is then used to smooth down the fabric. The edges of the overlapping fabric are then rubbed or rolled down with a smoothing tool.†

The method of finishing the fabric-covered portion consists in giving it a coating of filler, then two or three coats of undercoating grey paint, rubbing down the surfaces between each coat, and, finally, the whole propeller (fabric and wood) is rubbed down and given a coat of undercoating varnish, and one of finishing varnish, rubbing down between the two coats.

The I.A.S.B. specifies that 24 hours after gluing the fabric shall be given four coats of acetate dope, followed by two coats of varnish or enamel.

* See p. 412.

† Also see p. 414 for I.A.S.B. specifications for "Sheathing of propeller with fabric."

## CHAPTER XII

# MISCELLANEOUS METALS AND MATERIALS

## METALS

### Antimony.

ANTIMONY is a brittle metal of bluish-white colour, possessing a highly crystalline or laminated structure.

It melts at 630° C., and when heated in the open air burns with a bluish-white flame similar to zinc. It boils at 1440° C.

Antimony has a specific gravity of 6·7 to 6·8.

The coefficient of linear expansion is $12 \times 10^{-6}$.

The thermal conductivity is 0·040 at 100° C. and 0·044 at 0° C.

The specific heat between 17° and 92° C. is 0·0508.

Antimony is a constituent of certain commercial alloys, with lead, zinc, and tin, such as type-metal, Britannia metal, bearing metals such as Babbitts, white-metal, etc.

### Bismuth.

Bismuth is a light-reddish coloured metal, which is highly brittle and crystalline; it can be very readily pulverized.

Bismuth melts at 269° C. and boils at 1420° C.

The specific gravity is 9·823 at 12° C. and 10·055 just above the boiling point.

The coefficient of linear expansion is $15{\cdot}7 \times 10^{-6}$.

The thermal conductivity is 0·0194 at 18° C.

The specific heat is 0·0304 from 22° to 100° C.

Bismuth has a tensile strength of about 6400 pounds per square inch, with practically no elongation.

Bismuth expands upon cooling, the expansion taking place after solidification.

Bismuth is one of the most diamagnetic substances known, pieces of bismuth being repelled by a strong magnet.

Bismuth is a constituent of certain tin and lead alloys, and is used for alloys which expand upon cooling,* such as certain type and stereotype metals.

**Lead.**

Lead is a very malleable and ductile metal, having a silvery white crystalline appearance when freshly fractured.

Lead is not appreciably elastic, and it flows under very low stresses. The mechanical properties of lead are dealt with in Volume I of this work.

The specific gravity of pure lead is from 11·2 to 11·4 in the solid state and about 10·37 in the fluid state, so that there is an increase in volume of about 9·9 per cent. from the cold solid to the liquid state.

The tensile strength of lead varies from 1500 to 3000 pounds per square inch ; the compression strength is somewhat indefinite, but lead in a mould will withstand compressions up to 30 tons per square inch without breaking down, although the metal flows continuously. The flow pressure for ordinary lead specimens is 0·75 tons per square inch. The value of $E$ is 2,500,000 pounds per square inch.

The coefficient of linear expansion of lead is about $27 \cdot 6 \times 10^{6}$ per degree C.

The thermal conductivity of pure lead at 16° C. is ·083, and at 100° C. the value is ·082.†

The melting point of lead is 327° C., and the boiling point at atmospheric pressure 1525° C.

The specific heat of lead is 0·0305 between 20° and 100° C., and at 300° C. its value is 0·0338.

The electrical resistivity of lead at 18° C. is $20 \cdot 8 \times 10^{-6}$, and the temperature coefficient of resistance $43 \times 10^{4}$.

Lead oxidizes in air and is slightly soluble in pure water, but in water containing carbonates or sulphates a coating of

* See Table on p. 156.

† Kaye and Laby.

these lead salts is formed which protects the metal from further action.

Lead is a constituent of many commercial alloys, such as white-metal, bearing metals, lead bronzes, type-metal, soft solders, etc.

The effect of antimony and tin, in lead alloys, is to harden the metal.

## Magnesium.

Magnesium is a bright, silver-white metal, possessing malleability and ductility.

It is one of the lightest of the metallic elements, its specific gravity being 1·69 to 1·75, or about two-thirds that of aluminium.

It burns fiercely in air with a brilliant, white, dazzling flame, and is much used for flashlights, signals, and in pyrotechnical work.

It is practically non-corrosive, but a thin film of carbonate is formed in the presence of damp air, which protects it from further corrosion.

Magnesium melts at 633° C., and boils at 1120° C.

It has a coefficient of linear expansion of $25{\cdot}4 \times 10^{-6}$.

It has a thermal conductivity of 0·376 from 0° to 100° C.

The specific heat of magnesium from 18° to 99° C. is 0·246.

The electrical resistivity at 0° is $4{\cdot}35 \times 10^{-6}$.

Magnesium alloys with aluminium, and a series of these alloys is much used in commercial work.*

## Manganese.

Manganese is usually employed in the alloyed form, in commercial work, with iron, as ferro-manganese or spiegeleisen, analyses of which are given in Appendix I of the first volume of this work.

The specific gravity of manganese is 7·4, and its specific heat at 14° to 97° C. is 0·122.

* See pp. 45 and 46.

Manganese melts at 1260° C. and boils at 1900° C.

Manganese, when alloyed with iron, oxidizes rapidly in the air and it is much used as a deoxidizer of molten iron.

Manganese steel contains from about 7 to 20 per cent. of manganese, and it possesses marked strength and toughness, and is non-magnetic.

Manganese is present in all steels, whether carbon or alloy, in varying small amounts, and it forms a useful constituent.*

When present in copper-zinc or copper-tin alloys it adds to the strength and toughness, as in the case of manganese-bronze.

**Silicon.**

Silicon has a specific gravity of 2·3, and is a hard element which melts at 1200° C. and boils at about 3500° C., although there is some doubt as to the correct temperatures.

Silicon is the common constituent of silica ($SiO_2$), quartz, and glass, all of which are noted for their hardnesses.

Fused silica is used for electrical insulating properties at high temperatures.

It has a resistivity of the order of $10^{14}$ to $10^{19}$ ohm-centimetres, and this value decreases rapidly at higher temperatures.

Silica has a dielectric constant of 3·5 to 3·6, and a dielectric strength of 600 volts per mil.

The melting point is 1700° C. to 1800° C., and the coefficient of linear expansion from 0° to 100° C. is $0{\cdot}50 \times 10^{-6}$, and from 0° to 1000° C. $0{\cdot}54 \times 10^{-6}$.

The specific heat of crystalline silicon at 57° C. is 0·183.

Quartz is a form of silica, or oxide of silicon ($S_2O_2$), and is extremely hard ; it occurs in colourless transparent crystals of hexagonal and prismatic form. Quartz is often used as a high temperature optical substance, for the observation windows of combustion chambers, for sparking plug bodies, and similar purposes.

Fused silica ware is much used in chemical work, and for the

* See p. 384, Chap. VI, Vol. I.

leads of high temperature electrical thermometers, the exposed bulbs of thermometers, etc.

Quartz fibres can be drawn to very fine sizes, and these are employed for the suspensions of optical and electrical instruments. The tensile strength of these fibres is $10 \times 10^9$ dynes per square centimetre.

Silicon has an appreciable beneficial effect upon the strength of iron and steel when present in quantities up to 1·5 to 2·0 per cent.

In the case of mild steel there is practically no increase in the tensile strength until over 0·4 per cent. of silicon is present; when over this amount is present the tensile strength is increased but the ductility is reduced. About 1·5 to 2 per cent. is the maximum useful amount of silicon; above this there is a marked loss of ductility.

It is known that the addition of silicon to molten steel is useful, as it tends to reduce the formation of blow-holes.

Up to 2 per cent. in pig iron* improves the tensile strength and resistance to crushing; beyond this amount both of these strengths quickly diminish until, when about 6 per cent. of silicon is present, the tensile and compressive strengths are only about 50 per cent. of the maximum values.

Silicon is employed in metallurgical processes in the form of ferro-silicon, silico-spiegel, ferro-silicon-aluminium, silicon-aluminium, etc.†

Silicon bronzes and silicon-aluminium-copper alloys are noted for their high tensile strength, hardness, and non-corrodible properties.

## Tin.

Tin is a white lustrous metal, which is soft and fusible; it possesses little strength, and is principally employed in the alloyed form with other metals, to which it gives marked beneficial properties.

* For the influence of silicon on iron and steels, see Chaps. V and VI, Vol I.

† See Appendix I. "Ferrous Alloys." Vol. I.

Tin is commercially supplied in two grades, namely: Grade *A*, assaying not less than 99·75 per cent. of pure metal, and Grade *B*, assaying not less than 99 per cent. of pure metal.

The tensile strength of cast tin varies from 2500 to 5000 pounds per square inch, the average value being about 3500 pounds per square inch, with practically no elongation.

Tin melts at 232° C. and boils at 2270° C. under atmospheric pressure.

It has a coefficient of linear expansion of $21{\cdot}4 \times 10^{6}$.

The thermal conductivity of tin at 18° C. is 0·155.

The specific heat of tin is 0·0552 between 19 and 99° C.

The electrical resistivity at 18° C. is $11{\cdot}3 \times 10^{-6}$, and the temperature coefficient of resistance is $45 \times 10^{-4}$ between 0° and 100° C.

Compared with silver (100), the electrical and heat conductivities are 12·4 and 14·5 respectively.

The chief impurities in commercial tin are lead, iron, copper, and arsenic, and occasionally sulphur, silver, bismuth, and antimony.

Tin forms an important constituent of commercial non-ferrous alloys such as the bronzes, gun-metals, Delta-metals, bearing-metals, white-metals, solders, pewters, German silver, etc.

Tin is practically non-corrosive under ordinary atmospheric conditions, and it is widely used for coating copper and iron, domestic vessels, iron and steel sheets, etc.

## Zinc.

Zinc is a bluish-white metal which is moderately ductile and malleable, but to a much less extent than copper. It is ductile between 100° C. and 150° C., and can be worked to any desired shape, but outside these limits it becomes brittle.

Commercial zinc is supplied in the sheet form, as "spelter" (flat rectangular ingots from 1 to 2 inches thick), or in the granulated form.

The tensile strength of cast zinc varies from 2500 to 3500 pounds per square inch, with practically no elongation.

Zinc, after being compressed under a stress of 20 tons per square inch at 100° C., has a tenacity of about 11 tons per square inch.

Zinc melts at 418° C., and readily volatizes and burns in air with bluish-white fumes of zinc-oxide. Zinc boils at about 918° C.

The coefficient of linear expansion of zinc is about $26 \times 10^{-6}$.

The thermal conductivity of zinc is 0·265 at 18° C.

The specific heat of zinc is 0·093 between 20° and 100° C.

The electrical resistivity at 18° C. is $6{\cdot}1 \times 10^{-6}$, and the temperature coefficient of resistance is $37 \times 10^{-4}$ between 34° and 100° C. Compared with silver (100), the electrical and heat conductivities are 29 and 36 respectively.

Zinc is a useful constituent of non-ferrous alloys such as brasses, bearing-metals, certain bronzes, high tensile aluminium alloys, German silver, white-metals, etc.

Zinc is practically incorrodible under ordinary atmospheric conditions, and is therefore widely used as a protective coating for iron and steel, the surfaces being "galvanized" or zinc-deposited by various processes.*

## MISCELLANEOUS MATERIALS

### Asbestos.

Asbestos is a mineral fibre composed of hydrous silicate of magnesia with a small amount of iron oxide and alumina.

The following are the approximate ranges of composition of this material—

| | | |
|---|---|---|
| Silica .. .. | 40–41 | per cent. |
| Magnesia.. .. | 41·5–43·5 | ,, |
| Ferrous oxide .. | 0·9–2·8 | ,, |
| Alumina .. .. | 0·9–2·3 | ,, |
| Water .. .. | 13·0–14·0 | ,, |

Asbestos of the harsh fibre variety contains less water than the soft fibre kind, and if the latter be heated to a

* See "The Protection of Metal Surfaces," Chapter XII, Vol. I.

temperature that will drive off some of the water, there results a substance which is so brittle that it crumbles between the fingers.

Asbestos melts at a temperature of from 1200 to 1300° C.; it is an excellent heat insulator, and is widely employed in the form of asbestos mill-board, rope, twine, and wool for insulating furnaces, steam and exhaust pipes, boilers, etc. It is often combined with magnesium carbonate, hair, or with wool felt, and used for lagging steam pipes, an outer casing being employed for holding it in position.

Asbestos, when powdered or in the form of fibres, is often kneaded into a dough with water and used for stopping up holes and cracks in small muffles, furnaces, bearing-metal, shells, etc.

It is also frequently employed for making moulded shapes to withstand high temperatures; one well-known commercial form of this material (known as "Everite"*), being supplied as corrugated sheets varying in size from 4 to 10 feet long, by 30 inches wide, of ¼ inch thickness, and with corrugations of 3 inches pitch, the weight being 2 pounds per square foot.

This and similar asbestos cement roofing and building materials are fire-proof, non-conductive, acid and weather-proof.

The specific gravity of asbestos is about 3·1, a cubic foot weighing 193 pounds.

The electrical resistance is of the order of $16 \times 10^4$ ohms-centimetres, and in the composite forms, such as moulded asbestos and asbestos wood, it is much used for electrical insulators.

Asbestos is supplied commercially in the form of twine, rope, wool or flake, thin paper, mill-board, jointings, and moulded shapes, etc. It is used with a thin copper shell for internal combustion engine exhaust pipe and silencer joints and sparking plug washers.

* The British Everite Works, Ltd., Manchester.

**Bakelite.**

Bakelite is a well-known electrical insulating material, derived from the condensation product of phenol.

It is manufactured in three grades—

Grade *A* is the initial raw material, and is a liquid, paste, or soft solid substance.

Grade *B* is the product obtained by heating Grade *A*, and is a solid material, which softens upon heating, and which can be moulded in this state.

Grade *C* is obtained by heating *A* or *B*, and is a hard, infusible solid, resembling in appearance amber or resin, although it can be produced in a variety of shades and transparencies.

Bakelite is supplied commercially in the form of varnish, lacquer, enamel, cement, plastic moulding compositions, and hard, solid shapes.

It can be cast or moulded under hot pressure, and will receive metal inserts; in the solid state it can be machined and polished like ebonite or amber.

The maximum working temperature for electrical purposes is about 200° C., and Bakelite can be used for long periods at temperatures of from 100 to 150° C.

Bakelite is infusible, but it chars when sufficiently heated. It is not attacked by most solvents or acids, and is non-hygroscopic.

Bakelite *C* has a density of 1·26, and tensile and compressive strengths of 5000 and 26000 pounds per square inch respectively.

Its dielectric strength is 560 volts per mil, and it has a coefficient of linear expansion of 0·00011 per degree C.

Its resistivity at 26° C. is $5 \times 10^{11}$ to $3 \times 10^{12}$ ohms-centimetres, and the dielectric constant value 4·1 to 8·8.

Bakelite is frequently mixed with asbestos, wood-fibre, mica, and other insulating materials, and employed for insulating materials under trade names of Bakelite-asbestos, Bakelite-wood-fibre, etc.

**Celluloid or Xylonite.***

This material is composed essentially of pyrolin (soluble guncotton) and camphor (oil).

It can be produced in a variety of forms and colours, and is much used for fancy goods, imitation tortoise-shell, toys, and cheap, light moulded articles.

Celluloid is very slightly hygroscopic, and can be moulded into any form by softening in boiling water.

It is sometimes used for windows, wind-screens, hood panels, etc., but is apt to warp and cockle with atmospheric changes.

Celluloid is also used for covering metal steering wheels, bicycle handles, grips, and levers, in order to render them heat-proof and permanently clean.

Celluloid is very inflammable, and quickly ignites; for this reason much attention has been given to the question of rendering it fire-proof by mixing it with other ingredients, such as ferric perchloride in alcohol solution, bromide of camphor, and castor oil, etc.

The specific gravity is about 1·44, and the electrical resistivity from $2 \times 10^{10}$ to $8 \times 10^{10}$ ohms-centimetres.

Celluloid is soluble in amyl-acetate, and this liquid is often employed for cementing celluloid, accumulator repairs, and similar purposes; solutions of celluloid in amyl-acetate are sometimes used for covering bright steel and other metal surfaces for protection purposes.

**Cork.**

Cork is derived from the bark of certain trees, such as the cork oak (*quercus cuber*), and is a light-coloured, porous substance of very low density.

Its specific gravity is about 0·24, and a cubic foot of cork weighs about 15 pounds.

There is only one other commercial wood of lighter

* For non-inflammable transparent cellulose-base materials, see p. 325.

density, namely, *balsa*,* which weighs only 7 pounds per cubic foot.

The structure of cork consists of an aggregation of minute air-vessels, provided with thin, strong water-tight walls, so that if the material is compressed it behaves more like a gas than an elastic solid; unlike the behaviour of a spring, which exerts a pressure proportionate to the linear amount of compression, cork, when compressed, exerts a pressure which increases in a more rapid manner, and which varies, approximately, inversely as the volume.

The effect of the permeability of the cork to air, however, causes a gradual, but only partial, loss of compression elasticity under prolonged loads. The volume of the air-cells in cork constitutes about 50 per cent. of the whole bulk; if steeped in hot water, the volume of cork is increased from two to three times. This effect is made use of in connection with the bottling of liquids, the corks being treated in this way before forcing into the necks of the bottles.

The elasticity of cork is, to a certain extent, permanent; the corks of bottles of from 10 to 15 years of age invariably expand when withdrawn.

When compressed, there is a certain amount of permanent set, due to the escape of part of the air vessel contents, but when the load is released a very slow recovery occurs.

Cork is used for stoppers of all kinds, for heat insulation purposes (refrigerators, oxygen bottles, etc.), sound-proof linings to rooms, floats for carburettors, washers for the caps of vessels and tanks, vibration insulators, life-belts and life-buoys, etc.

### Chatterton's Compound.

This is a hard black substance used for electrical insulating and water-proofing articles. It is composed of three parts of gutta-percha, one part rosin, and one part of Stockholm tar. This substance is applied by melting it, a moderate

* See p. 218.

temperature only being required, and running it in, or for small work, with the aid of a hot iron.

It is very useful for stopping up air-leaks in air pipes and experimental apparatus ; it resembles the well-known "heel ball" of the shoe-maker in many of its properties.

**Felt.***

Felt is a material composed of wool, or wool and cotton, in a more or less compressed condition, the former being known as the "all-wool," and the latter as the "cotton-mixed" felt. The quality of the felt depends upon the ingredients, and the purpose for which it is required.

There are a number of grades of wool used in felts, which may be roughly classified as follows—

(1) Fine Wool, such as Virginia stock, long or short fibre, straight and kinky.

(2) Coarse Wool, such as Virginia stock, long or short, but usually straight and with little kink in it.

(3) Wool Shoddies, from old scrap wool felt or various wool fabrics ; these have less length of staple or fibre than Virginia stock, and are used in the cheaper grades of felt, more particularly in cotton mixed felts.

For hard felt, it is necessary to use practically all wool, as cotton cannot be hardened in the felting or fulling process.

When cotton is used with wool shoddies, it is necessary to use glue sizing in order to make the felt hard, but glue-sized felts are not, in general, very satisfactory.

There is a variety of different felts upon the market, and the quality of these varies considerably, so that it becomes necessary to devise certain standard characteristics, such as the composition, density, and hardness, for felts for special purposes.

It is possible to employ a hardness testing instrument of the schleroscope type, using a special scale, in order to

* For fuller information the reader is referred to "Felt in Aircraft Construction," by S. W. Widney, *Aerial Age*. (Reproduced in *Flight*, 14th Feb., 1918.)

determine the hardness of felt; the hardness property affords an accurate and convenient means for estimating the quality.

It is also necessary to specify the percentage of wool and cotton, and to limit the amount of foreign matter, such as dirt or grit.

In some respects, felt, in its cushioning effects, resembles cork in the action of the imprisoned air and elastic fibres.

Felt is used in engineering work to eliminate noise and vibration, and for heat resisting coverings; it is also used in the form of pads and wicks for lubricating purposes.

Felt washers and packings are widely used in automobile work for preventing oil leakage from engine bearings, gear-box, and differential housings, etc.

In aeronautical work, felt is used for packings and vibrationless fittings, such as for insulating instruments and instrument boards from the vibration of the engine, for lining metal clamping bands for the fuel tanks, lockers, camera boxes, and similar noise and vibration eliminating purposes.

## Ferodo.*

Ferodo is the name given to a group of materials having high frictional qualities, and which are used for brake-linings, friction clutches, discs, and similar purposes.

Ferodo is supplied in two principal forms, namely, the cotton-bonded and the brass-wire woven asbestos varieties.

The cotton-bonded type is made of compressed cotton fibre impregnated with a special fluid, and it gives a higher coefficient of friction than the asbestos variety, but does not withstand such high temperatures.

The asbestos type consists of impregnated compressed asbestos, with numerous fine brass wires running through it. The object of the wires is to hold the material together and to conduct the heat, generated by the friction, away.

These materials possess high coefficients of friction, and, unlike leather, retain a fairly high value over considerable

* Manufactured by the Herbert Frood Co., Ltd.

ranges of pressure, temperature, and speed. They are also only slightly affected, in frictional properties, by water and oil.

The asbestos variety will withstand high temperatures, which would rapidly char leather, without much diminution in the friction coefficient.

The value of the coefficient depends a little upon the pressure, temperature, and speed, and for the bonded asbestos type varies from 0·25 to 0·35, when in contact with cast iron or steel.

Temperatures as high as 200° C., pressures of 100 pounds per square inch, and rubbing velocities of 6000 feet per minute, can be employed with this material; the coefficient of friction does not differ appreciably from the value 0·30 under these conditions.

The value of the coefficient for the cotton fibre varies from 0·4 to 0·65; for pressures of 50 to 80 pounds per square inch, temperatures of 100° C. and rubbing velocities of 2000 feet per minute, the value is 0·42 to 0·46.

The coefficient of friction is higher for the cotton fibre type, and its value increases with the temperature up to the charring point at 150° C. to 180° C.

For low pressures (10 to 20 pounds per square inch) and ordinary temperatures, the value of the coefficient varies from 0·2 to 0·3.

The effect of lubrication (mineral oil) is to lower the value of the coefficient to 0·05 to 0·2 in the case of the asbestos variety, to 0·2 to 0·3 in the case of the cotton type.

The cotton variety shows an extremely low rate of wear and many motor 'bus brakes lined with this material have run 20,000 miles without appreciable wear.

The amount of energy absorbed by a good brake lining varies from 100,000 to 120,000 foot-pounds per square inch per minute, for pressures varying from 50 to 80 pounds per square inch, and coefficient of from 0·3 to 0·5 (in the dry state).

These materials are much used for lining the brakes of automobiles and motor cycles, winding engines, cranes, and

similar purposes, for the clutches of cars, and for friction drives of all purposes, etc.

When Ferodo is employed to replace leather in car clutches of the cone type, lighter springs must be employed, otherwise the clutch will work more fiercely. An angle of from 18° to 20° is recommended for cone clutches. The original surface of the material, as supplied, does not give such a high coefficient of friction, as when it is worn off and the real material underneath exposed.

There are many similar brake and clutch lining materials of this type, using asbestos or fibre of some kind, which give fairly high frictional and wearing properties.

One variety, consisting of wire woven asbestos impregnated and coated with rubber, gives excellent results at medium speeds and pressures.

The properties of leather and fibre, from the point of view of their suitability for brake materials, are discussed under their separate headings.

**Fibre.**

Vulcanized or red fibre is a hard, dense material composed of paper or cellulose made from cotton rag stock, together with zinc-chloride and colouring matter, either aniline dyes or pigments.

The material is made in the form of a number of paper-like laminae, pressed together in the wet state under very great pressure, followed by slow drying, which is accompanied by a contraction in volume.

Fibre is naturally hygroscopic for this reason, and in the presence of moisture swells again, but, not being isotropic, it swells unequally in the different directions.

The hygroscopic property of fibre is illustrated by the following results of tests,* in which different sets of four samples of fibre were exposed for periods of 48 and 60 hours respectively in saturated damp atmospheres and in cold water.

* "The Less Satisfactory Materials of Aircraft Construction," G. S. Walpole. *Aeron. Journ.*, Jan.-Mar., 1917.

## TABLE CXXXVII.

### (1) Fibre Samples Exposed for 60 Hours to Damp Atmospheres.

| *Sample No.* | *Percentage increase in weight after 60 hours.* | | |
|---|---|---|---|
| | *38 per cent. humidity.* | *75 per cent. humidity.* | *100 per cent. humidity.* |
| 1 | 0·175 | 3·65 | 3·67 |
| 2 | 0·72 | 4·60 | 4·60 |
| 3 | 0·78 | 4·80 | 5·17 |
| 4 | nil. | 0·2 | 0·25 |

It will be observed that the maximum weight increase is about 5 per cent., and that the particular sample No. 4 shows only a very small increase.

## TABLE CXXXVIII.

### (2) Fibre Samples Immersed in Cold Water for 48 Hours.

| *Sample No.* | *Percentage increase in Weight.* |
|---|---|
| 1 | 51·2 |
| 2 | 44·3 |
| 3 | 44·2 |
| 4 | 0·52 |

## TABLE CXXXIX.

### (3) Fibre Samples Exposed to Saturated Water Vapour for 48 and 60 Hours.

*Increase in Dimensions due to Moisture Exposure.*

| *Sample No.* | *Saturated water vapour for 60 hours.* | | *Water for 48 hours.* | |
|---|---|---|---|---|
| | *Increase in length.* | *Increase in breadth.* | *Increase in length.* | *Increase in breadth.* |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 1 | 3·81 | 1·03 | 37·9 | 7·0 |
| 2 | 4·61 | 1·02 | 44·4 | 3·5 |
| 3 | 4·02 | 1·14 | 35·4 | 2·9 |
| 4 | 1·61 | 0·16 | nil | nil |

It will be observed from these results that the ordinary commercial samples 1, 2, and 3, are markedly affected by moisture, and that when soaked in water swell considerably in length and slightly in breadth (*i.e.*, according to the direction of the "grain").

Sample No. 4, which was made from material water-proofed before compression, although it has a grain, shows very little expansion after moisture exposure.

This material is very suitable for the fibre bushes of magnets, and when used the material should be arranged to swell axially, so that there is practically no risk of jamming the contact-breaker lever.

Fibre is used for a variety of purposes in the form of paper, sheet, slabs, tubes, etc.

In the form of thin sheets of from 1 to 4 millimetres thickness it is much used for carburettor joints, petrol tank cap joints, washers, packing, and insulators.

Fibre tubing is employed for carrying the high tension leads of car and aircraft engines.

Fibre is also much used as an electrical insulating material, although its resistivity is fairly low for dielectrics, being of the order of $10^7$ to $10^{10}$ ohms-centimetres. Certain hard dry varieties, however, have a resistivity of $7 \times 10^{13}$ ohms-centimetres.

The dielectric strength of thicknesses varying from $\frac{1}{8}$ inch to 1 inch is given by Parshall and Hobart as 10,000 volts, and by Hendricks as 200 volts per mil. at thicknesses of 50 to 150 mils, 160 volts per mil. at thicknesses of 0·4 inch, 100 volts per mil. at 0·7 inch, and 90 volts per mil. at 1·0 inch.

The specific gravity of fibre varies from 1·0 to 1·5, according to the grade, average samples being about 1·4.

The tensile strength varies from 10,000 to 20,000 pounds per square inch, and the compressive strength from 35,000 to 60,000 pounds per square inch.

Fibre is supplied commercially in a number of grades

and varieties, known by various trade names, such as red-fibre, hard-fibre, horn-fibre, leatheroid, fish-paper, indurated-fibre, waterproof-fibre, etc.

When the fibre pulp is treated with Bakelite, a material is obtained having a much higher resistivity ($1 \cdot 1 \times 10^{13}$ ohms-centimetres) and non-hygroscopic; this material, which is known as "Bakelite-dielectro," is a hard, tough substance which cannot be moulded, but is impervious to hot water, oils, and ordinary solvents.

Fibre has been employed for brake blocks, more especially for small machinery and cycles, but it is inferior both in frictional and wearing qualities to the asbestos and other bonded brake materials, such as Ferodo. The co-efficient of friction varies from 0·3 to 0·4, and the charring temperature 150° to 200° C. Oil reduces the coefficient very considerably.

## French Polish.

This is usually prepared by dissolving 3 ounces of shellac in 1 pint of alcohol (spirits of wine). It may be darkened by adding "dragon's blood."

For woodwork, the surface is well sand-papered, finishing with the finest grade, and is then given a coat of linseed oil, which acts as a filler. A pad of cotton wool is then given a smearing of linseed oil, and a piece of fine, soft cotton rag is placed over it; the polish is applied to the cotton rag, and the wood is rubbed in one direction with same until it shows a polished appearance.

This coating should be given from 16 to 36 hours or more to dry, and another coating of polish should be then applied lightly and in one direction.

For the best results the wood is rubbed down between the first two or three coats and several coats are given. Any liquid filler may be employed, where the grain effect is not essential.

**Glass.**

Glass is made from (*a*) silica, (*b*) salts of alkali metals, and (*c*) salts of bases other than alkalies, as follows—

(*a*) Sand or felspar.

(*b*) Sodium sulphate, or carbonate, or potassium carbonate.

(*c*) Red lead, limestone, chalk, barium carbonate, magnesium carbonate, zinc oxide, alumina, etc.

In general, glasses rich in silica and lime are hard, whilst those containing much alkali, lead, or barium are soft.

The following are typical analyses* of different glasses—

VERRE DUR GLASS.—Silica ($SiO_2$) 71 per cent., sodium oxide ($Na_2O$) 12 per cent., potassium oxide ($K_2O$) ½ per cent., calcium oxide 14 per cent., aluminium oxide ($Al_2O_3$), and magnesium oxide (MgO) 2 per cent.

JENA GLASS.—Silica 72 per cent., boron oxide ($B_2O_3$) 12 per cent., sodium oxide ($Na_2O$) 11 per cent., aluminium oxide ($Al_2O_3$) 5 per cent.

The silica content ranges from 50 to 75 per cent. in the different glasses.

FLINT GLASS is a dense glass which contains lead, and which possesses a high refractive index and dispersive power; it is used for lenses of telescopes, microscopes, and optical instruments.

CROWN GLASS was the name usually applied to lime-silicate glass, but it is now employed for glasses of low dispersive power.

It is not proposed to go into the optical or thermal properties of glasses here, but for full information the reader is referred to works upon optics and heat.†

Glass is hard and brittle, its tensile strength varying from 2000 to 10,000 pounds per square inch, according to the

* "Physical and Chemical Constants," G. W. C. Kaye and T. H. Laby. (Longmans, Green & Co.)

† "Glass Manufacture," W. Rosenhain.

"Chemical and Physical Constants," Kaye and Laby. (Longmans, Green & Co.)

quality, and its compression strength from 13,000 to 40,000 pounds per square inch.

The following results were obtained* from tests upon different kinds of glass bars, plates, cylinders, and cubes.

## TABLE CXL.

### Mechanical Properties of Different Kinds of Glass.

| *Name of glass.* | *Form in which tested.* | *Mean specific gravity.* | *Mean tensile strength in pounds per sq. in* | *Mean compressive strength in pounds per sq. in* |
|---|---|---|---|---|
| Best flint glass .. | ½ inch diameter bars | — | 2413 | — |
| | Thin plates | 3·078 | 4200 | — |
| | Cylinders ¾ inch dia. | — | — | 27582 |
| | Cubes 1 inch square | — | — | 13130 |
| Common green glass .. | Bars | — | 2896 | — |
| | Thin plates | 2·528 | 4800 | — |
| | Cylinders | — | — | 39876 |
| | Cubes | — | — | 20206 |
| Extra white crown glass .. | Bars | — | 2546 | — |
| | Thin plates | 2·450 | 6000 | — |
| | Cylinders | — | — | 31003 |
| | Cubes | — | — | 21867 |

The value of the elastic modulus for glass is about 4300 to 5000 tons per square inch for Jena crown glass and 3400 to 3700 tons per square inch for the Jena flint variety.

The moduli of rigidity is from 1700 to 2500 and 1500 to 1800 tons per square inch respectively, and the corresponding values of Poisson's ratio 0·20 to 0·27 for crown and 0·22 to 0·26 for flint glass.

The specific gravity of crown glass varies from 2·20 for the silicate crown variety up to 3·60 for the heavy barium crown type; for the silicate flint variety it is about 3·5, for the borosilicate flints 2·85, for the barium flints 3·95, and for heavy flint glass 5·0 to 5·9.

The coefficient of linear expansion varies from 0·000008 to 0·0000095 per degree C.

The thermal conductivity of soda glass is about 1·3 to

* Kent's "Mechanical Engineers' Pocket Book." (John Wiley & Son.)

$1{\cdot}8 \times 10^3$ (c.g.s. units), of flint glass $2 \times 10^3$, and crown window glass $2{\cdot}5 \times 10^3$.

The insulating properties of glass are well known, the resistivity being of the order of $10^{13}$ to $10^{18}$ ohms-centimetres at ordinary temperatures, but decreasing rapidly as the temperature increases. Potash glass has a higher resistivity than soda glass, and annealing increases the resistivity. Moisture condenses on the surface of glass, and destroys its electrical insulating properties, due to surface leakage.

The dielectric constant varies from 5·5 to 10, and the dielectric strength from 150 to 300 volts per mil.

UNSPLINTERABLE GLASS.—There are several patented processes for rendering glass unsplinterable, amongst which may be mentioned the method used for the glass of factory buildings, houses, and ships, of casting or running molten glass around flat wire netting of fairly small mesh, so that the resulting sheets contain the wire netting in about their central planes.

Another method, invented by M. Benedictus, and known as Triplex* glass, consists of two pieces of glass with a sheet of xylonite or celluloid between, adhesion being effected by the use of a strong transparent cement, under great pressure.

When a composite sheet of this type is struck a heavy blow, it cracks in a large number of places, radiating from the point of impact, but it does not fall into pieces, remaining plane as before. Occasionally a little powdering at the point of impact occurs.

This material is widely used for the wind-screens of aeroplanes and cars, for goggle-glasses, bulkhead door illuminators, port-holes, periscopes of submarines, observation windows for armoured cars, field glasses, and even for spectacles.

Its use upon aeroplanes has resulted in several instances in the saving of the eyes, and sometimes the lives, of the occupants, during fighting in the air, or in accidents. The effect of the celluloid layer in this glass is to give it a slight yellow

* Manufactured by the Triplex Safety Glass Co., London.

colour, which is not, however, detrimental for the majority of purposes.

Triplex in thicknesses of from 1 to 2 inches is bullet proof at ordinary ranges; the effect of the impact of a bullet, in the case of the smaller sizes, is to punch a clean hole, with short radiating cracks around it.

### Gutta-percha.

Gutta-percha is the name given to certain varieties of gum, similar to those from which rubber is derived, the best qualities of which are obtained from the Isonda gutta-tree, which grows in Borneo, Sumatra, and Malacca. The gum *Balata*, which is similar to gutta-percha, is derived from trees in Venezuela.

Gutta-percha is produced from the latex or gum in the same manner as rubber, but it is generally used in the pure state, and is not usually vulcanized, pigmented, or filled.

The density of gutta-percha varies from 0·97 to 0·98, and its electrical resistivity is about $34 \times 10^9$ ohms-centimetres, the apparent dielectric constant being 2·86.

Gutta-percha is much used for insulation purposes, for covering submarine cables, insulations, splices, and joints.

### Insulating Tape.

This material, which is also known as rubber-treated or adhesive tape, consists of fabric tape (linen or cotton) impregnated with plastic or sticky gum, the base of which is rubber gum. Fillers and bituminous substances are used to adulterate the gum; the best grades contain the more expensive rubber gums.

The impregnated fabric possesses fair electrical insulating properties, and when slightly warmed can be made to adhere to itself and to metal, wood, and other surfaces.

It is much used for electrical repair work, temporary lead insulations, for preventing air leaks in petrol engine induction pipes, for preventing nuts and other parts shaking loose, for

preventing rattle of adjacent parts on automobiles and aircraft, etc.

One typical example of its use may be mentioned in the case of the bracing wires of aircraft; wherever such wires cross in about the same plane, insulating tape is usually employed to insulate the wires against vibration, rubbing, and noise effects.

## Leather.

Leather is drived from the hides of domestic animals, by tanning processes.

It is much used in engineering work for driving belts, friction lining material, washers for hydraulic work, cocks and taps, etc.

The specific gravity of leather is from 0·90 to 0·98, a cubic foot weighing about 57 to 60 pounds, on the average.

The tensile strength of single, ordinary tanned leather belting varies from 3000 to 5000 pounds per square inch, for Helvetia single leather from 5500 to 6000 pounds per square inch; for double, ordinary tanned leather 2000 to 3600 pounds per square inch, for double Helvetia leather 4000 to 5500 pounds per square inch.

An ordinary single leather belt will transmit 1 horse-power per inch width at 1000 feet per minute.*

It is usual to allow a working tension of 33 pounds per inch width, or about 165 pounds per square inch of section.

The coefficient of friction of leather is very high for low pressures, the value varying from 0·7 to 0·8 for temperatures below 30° C. and for pressures lower than 20 pounds per square inch.

The coefficient falls off fairly rapidly with temperature rise, as the values on next page show, in the case of leather belting material in contact with cast iron.

* For further information upon the subject of belting the reader is referred to engineering pocket books.

## TABLE CXLI.

### Effect of Temperature upon the Frictional Properties of Leather on Cast Iron.

*Pressure = 15 pounds per square inch. Speed = 2000 f.m.*

| Temperature ° C. .. | 20 | 40 | 60 | 80 | 100 | 120 |
|---|---|---|---|---|---|---|
| Coefficient of friction .. | 0·80 | 0·795 | 0·77 | 0·72 | 0·62 | 0·25 (charred) |

The effect of increased pressure is shown by the following results—

## TABLE CXLII.

### Effect of Pressure upon the Frictional Properties of Leather on Cast Iron.

*Temperature = 40° C. Speed = 2000 f.m.*

| Pressure in pounds per square inch | 15 | 25 | 40 |
|---|---|---|---|
| Coefficient of friction .. .. | 0·795 | 0·675 | 0·515 |

The effect of increased speed is also to improve the frictional coefficient; at low speeds (below 500 f.m.) the values are about 65 per cent. of the values for medium speeds.

At 100° C., and with 50 pounds per square inch in pressure, the value of the coefficient is 0·3, and at high speeds 0·5.

The disadvantage of leather, from the point of view of a brake material, is that the working pressures and speeds are much lower than in the case of materials such as Ferodo, on account of charring, so that for the same area it does not absorb nearly so much work.

The coefficients of friction for moderate pressures and speeds in the wet, greased, and oiled conditions, when in contact with steel or cast iron, are about 0·35, 0·23, and 0·15 respectively.

**Linseed Oil.**

Linseed oil is a vegetable oil obtained from the seeds of flax, and it is widely used as a constituent of paints and varnishes.

It has a specific gravity of 0·932 to 0·936 at 15° C.

Boiled linseed oil, when exposed to ordinary atmospheric conditions, becomes oxidized into a viscous or hard film; this effect is accelerated by the action of heat, or drying agents.

The raw linseed oil is chiefly used with white lead colours, and the boiled variety (which tends to darken paints) with dark colours, such as reds, greens, browns, blues, and black pigments.

The method of obtaining boiled linseed oil* is to add to each gallon of raw oil about 6 ounces of litharge and 2 ounces of red lead, and to heat for a few hours at about 120° C. to 200° C., afterwards running off the clear oil when cold.

Linseed oil may be bleached by exposing to strong sunlight in thin glass jars.

The drying quality of linseed oil is usually tested by painting a piece of glass and exposing to a temperature of 38° C., noting the time required to dry.

Linseed oil is widely employed in oil varnishes, with soluble gums such as amber, copal, and gum animi; these varnishes take a much longer time to dry than the spirit varieties, but give more elastic, harder, and more durable results.

The name *linoxyn*, or *oil-rubber*, is given to the rubbery material formed by the oxidation of linseed oil. It is sometimes used for so-called "artificial" rubbers, with other filling ingredients.

Lithographic oil is made by heating refined linseed oil until it becomes thick and viscous, without the use, however, of drying agents.

* The oil is not "boiled" in the real sense of the word.

**Mica.**

Mica is a refractory material and is a double silicate of alumina, or magnesia, and potash or soda, and containing various impurities such as iron, which gives it a grey or black foliated appearance, magnesia, which tends to darken it, and aluminium silicate, which helps to render it more transparent.

Mica is obtained in the form of laminated sheets, which can be readily split into thin sheets as small as ·006 millimetre in thickness. The best grades of mica come from India and Canada, the American or domestic grades coming last.

White or Muscovite mica is much used for electric and other heating apparatus; transparent lamp and gas chimneys, and panels in oil and gas stoves are made of white mica.

The largest commercial sizes of cut mica sheets are about 8 or 10 inches square, or 10 × 8 inches, and are much more expensive compared with smaller sizes, so that it is now usual to employ for electrical purposes, where possible, moulded or built-up mica sheets, made from small flakes or ground mica, known under various commercial names, such as Micanite, Mica-paper, Mica-cloth, Megomic, etc.

Pure mica is one of the best electrical insulating materials known, as it not only possesses a very high resistivity but also is capable of withstanding high temperatures.

The resistivity of mica varies with the grade or source of origin, but the following values* represent the more reliable results—

TABLE CXLIII.

ELECTRICAL PROPERTIES OF MICA.

| *Source.* | *Resistivity in ohm-centimetres* ($\times 10^{12}$). | *Dielectric constant.* | *Disruptive strength in volts per millimetre.* |
|---|---|---|---|
| Bengal.. .. | 15–133 | 2·5–5·5 | 50,000–80,000 |
| Madras .. | 7–118 | 2·8–4·7 | 40,000–120,000 |
| Canada .. | 0·44–22 | 2·9–3·0 | 80,000 |
| South America | 39 | 5·9 | 40,000–90,000 |

* *Vide* "Standard Handbook for Electrical Engineers. (McGraw Hill Book Co.)

"Mica, Its History, Production, and Utilization," H. Zeitler.

"Mica," Canadian Dept. of Mines Publication, 1912.

The specific gravity of mica is about 2·7 to 3·1.

Its specific heat varies from 0·206 to 0·208.

The melting point of mica is 1200 to 1300° C.

The insulating properties of mica are retained up to 600° to 800° C., the effect of increasing temperature being to disintegrate the laminae into small flakes.

Amber mica, of Canadian origin, is less affected by heat than the other varieties, and is somewhat softer; it is used for the armatures of motors and dynamos, as it is not so hard as the domestic grades and wears down at approximately the same rate as the copper segments, so that hard mica ridges are not formed.

Mica is used for numerous electrical purposes as an insulator; it is employed, in the form of a series of washers, tightly clamped and turned to size, for the insulation of high-grade motor and for nearly all kinds of aeroplane sparking plugs.

**Porcelain.**

The grades of porcelain employed for electrical purposes contain silica, clay, and felspar; the three felspars which are used comprise orthoclase (or potash felspar), albite or indianite (or soda felspar), and anorthite (or lime felspar).

The clays employed are china clay or kaolin and ball clay.

The following is a standard composition—

| | |
|---|---|
| Quartz | 30 per cent. |
| Kaolin | 50 „ |
| Felspar | 20 „ |

The felspar acts as a flux and tends to unite the other constituents when fused.

Porcelain may be made either by the *dry process*, in which the ingredients are mixed and moulded under hydraulic pressure and then "fired" in the usual way, or by the *wet process*, in which the materials are mixed with water, into a

wet plastic cake, moulded or worked to shape, dried, and after dipping in the glazing bath, placed in the kiln before "firing." Most electrical porcelains are made by the wet process.

The glazing mixture contains more flux than the porcelain mixture, so that it vitrifies at a lower temperature. The shrinkage during manufacture, from the clay, amounts to from 10 to 20 per cent.

Dry process porcelain is usually porous and is not suitable for high voltages.

Electrical porcelain has a specific gravity of from 2·3 to 2·5. It is not affected by oils, acids, alkalies, or water, and it should not be porous in the unglazed condition.

The coefficient of linear expansion varies from 2·5 to $5{\cdot}5 \times 10^{-6}$ per degree C.

The specific heat is 0·17 and the thermal conductivity is 0·045 that of silver.

The electrical resistivity of unglazed porcelain is of the order of $10^{14}$ to $10^{15}$ at ordinary temperatures, but decreases fairly rapidly with temperature increase. At high temperatures it becomes a conductor, so that it is not suitable for electrical furnaces.

The dielectric constant is from 4·4 to 6·8, and at low frequencies the disruptive voltage is about ·30 kilowatts for a thickness of 0·1 inch and about 110 kilowatts for a thickness of 0·5 inch.

The tensile strength of American porcelain varies from 700 to 2000 pounds per square inch, the average value being 1400 pounds per square inch.

The compressive strength is about 15,000 pounds per square inch.

European porcelains have a tensile strength of from 4000 to 6000 pounds per square inch, and a compressive strength of about 65,000 pounds per square inch.

The modulus of elasticity is about 2,500,000 pounds per square inch.

For other information regarding porcelains the reader is referred to the footnote references.*

Porcelain is widely used for electrical insulators, fuse-boxes, large and small switches, insulated handles, electrical connexions, sparking plug body insulators, outside live wire insulators, etc.

* "Electrical Porcelain," E. E. F. Creighton. *Proc. A I.E.E.*, May, 1913.
"Electrical Conductors," F. A. C. Perrine. (D. Van Nostrand Co., New York.)
"High Tension Porcelain Insulators." *Journ. I.E.E.*, July, 1912.
"High Frequency Tests of Line Insulators," L. E. Imlay and P. H. Thomas.

# CHAPTER XIII

# VENEERS AND PLYWOODS

## VENEERS

THE name " veneer " is given to very thin layers or sheets of wood, cut or sawn from logs, or pieces of wood.

These layers are used for two principal purposes, namely, for decorative work and for constructional work.

In decorative work, special timbers such as walnut, cedar, mahogany, etc., giving fine grain effects, are employed, and the thin layers or veneers are glued on to the base-wood forming the strength members. This well-known method is applied to the finishing of the surfaces of pianos, cabinets, panels, and furniture work in general.

In constructive work, veneer is used in several layers with the grains in different directions, glued together. Plywoods, built-up surfaces, and coverings for aircraft bodies and wings, etc., are examples of the use of veneer for constructional work.

### Aircraft Coverings.

Thin veneer of cedar or mahogany is sometimes used for wing coverings and for floats. The veneer is strengthened by gluing a cotton or linen fabric to one or both sides, with a waterproof casein glue.

The effect of coating a veneer with fabric is to enable it to take tensile stresses without breaking, and to protect it. A piece of cedar or mahogany veneer of from $\frac{1}{12}$ to $\frac{1}{18}$ inch thickness can be bent to a radius of about $\frac{1}{4}$ inch or less without cracking.

This type of covering can be employed for aeroplane wings, more particularly for the portion between the leading

edge and the first spar, and for the under, or both, surfaces of the lower wings of flying boats and seaplanes.

The author has experimented with various combinations of veneers and fabrics, and finds that the above is about the best combination for general work.*

## TABLE CXLIV.

The following table† gives the principal particulars of the materials used in the main structure and planing extensions of flying boat hulls—

| *No.* | *Type.* | *Area of Hull.* | *Thickness of Skin.* | *Timbers.* | *Stringers.* | *Thickness of Planing Extension.* |
|---|---|---|---|---|---|---|
| | | *Sq. feet.* | | | | |
| 1 | 180 H.P. | 276 | $\frac{5}{16}$ inch spruce and fabric ribband carvel | $\frac{3}{4} \times \frac{5}{8}$ inch ash spaced $6\frac{1}{2}$ ins. | Ribbands $1 \times 1\frac{1}{4}$ inch ash. | $\frac{3}{16}$ inch mahog., diag. $\frac{5}{16}$ inch mahog., fore and aft. |
| 2 | 240 H.P. | 192 | 2 skins carvel sewn. | — | — | — |
| 3 | — | 202 | Top sides $\frac{3}{32}$ in. $\frac{1}{8}$ in. fore and aft bottom. skins cedar $\frac{3}{32}$ in. diag.; $\frac{3}{16}$ in. fore and aft mahog. | $\frac{3}{4} \times \frac{5}{16}$ in. elm spaced 4 ins. | $\frac{3}{4} \times \frac{5}{8}$ in. spruce. | — |
| 4 | 640 H.P. | 1172 | $\frac{3}{32}$ in. mahog. diag. $\frac{3}{16}$ in. cedar fore and aft. | $\frac{7}{16} \times \frac{5}{16}$ in. rock elm, spaced $2\frac{1}{2}$ ins. | $1\frac{3}{4} \times \frac{3}{4}$ in. to $\frac{5}{8}$ in. spruce. | 3 skins, 2 inner; diag. skin, $\frac{3}{32}$ in. and 1 outer fore and aft, $\frac{5}{16}$ in. mahog. |
| 5‡ | 400 H.P. | 311 | $\frac{3}{32}$ in diag.; $\frac{1}{8}$ in. fore and aft, mahog. | $\frac{7}{16} \times \frac{3}{4}$ in. spaced $4\frac{1}{2}$ ins. | — | $\frac{3}{32}$ in diag. mahog. $\frac{3}{32}$ in. fore and aft.§ |
| 6 | 200 H.P. | 186 | $\frac{3}{32}$ in. diag. cedar, $\frac{1}{8}$ in fore and aft. | $\frac{1}{2} \times \frac{3}{16}$ in. elm spaced $2\frac{1}{2}$ ins. | $\frac{3}{4} \times \frac{5}{8}$ in. spruce. | 3 skins, $\frac{3}{32}$ in. and $\frac{1}{8}$ in. cedar and $\frac{1}{4}$ in. mahogany. |
| 7‡ | 200 H.P. | 173 | $\frac{3}{32}$ in. mahog., stringer carvel. | $\frac{3}{16} \times \frac{1}{2}$ in. elm spaced $1\frac{3}{4}$ in. | $1\frac{1}{2} \times 1\frac{1}{2} \times \frac{1}{4}$ in. spruce | $\frac{1}{16}$ in. diag. cedar, $\frac{1}{8}$ in. fore and aft mahogany§ |
| 8‡ | 720 H.P. | 560 | 2 skins mahog. and fabric between $\frac{3}{32}$ in. diag., $\frac{5}{32}$ in. fore and aft out. | $\frac{5}{16} \times \frac{1}{2}$ in. spaced $1\frac{3}{4}$ in. | $1\frac{1}{2} \times \frac{1}{8}$ in. spruce. | 2 skins mahog., fabric between $\frac{3}{16}$ in. fore and aft, $\frac{3}{32}$ in. diag., $\frac{5}{32}$ in. fore and aft, $\frac{5}{32}$ in. diag. (aft).§ |
| 9‡ | 1875 H.P. | — | Ditto | Ditto | Ditto | Ditto |
| 10‡ | 2400 H.P. | 1230 | $\frac{3}{32}$ in. at 2·036 pounds per sq. ft. (2 skins). | $\frac{5}{16} \times \frac{3}{4} \times 2$ ins. | $2\frac{1}{2} \times \frac{5}{16}$ in. *I*-fillets $\frac{5}{16}$ in. and $\frac{5}{8}$ in. | — |

* Also see Table CXII, p. 327.

† The *Aeron. Journ.*, Sept, 1920. "Note on Flying Boat Hulls."

‡ Weights per square foot of hull: (5) 2·43 pounds; (7) 0·957 pounds; (8) 1·36 pounds; (9) 1·36 pounds; (10) 2·036 pounds.

§ Weights per square foot of planing extensions: (5) 2·4 pounds (7) 1·2 pounds; (8) 1·2 pounds.

**Manufacture of Veneer.**

There are three processes of cutting veneer,* namely: (*a*) Rotary cutting; (*b*) Sawing; and (*c*) Slicing.

The most important method is the rotary cutting one, and it consists in holding the log between centres in a kind of lathe, so that it can be made to rotate; as it rotates, a long knife is caused to move forward towards the axis a definite distance for each rotation, and this knife peels off a strip of veneer of length equal to the length of the log and of width depending upon the diameter of the log and the thickness of the veneer. The width is in reality that of the relative spiral path of the cutting knife. The logs, which vary from about 4 to 8 feet in length, are usually thoroughly steamed in the first place to soften the wood. The steaming process is invariably carried out with woods containing frost, or hardwoods, but with softwoods, unless the thickness exceeds about $\frac{3}{16}$ inch, most species can be rotary cut without a preliminary steaming. The smallest rotary chuck is about 6 inches in diameter, so that this is the limiting diameter to which the logs can be cut, and represents the wasted portion of the log from the point of view of veneer. The heartwood is often unsound, so that the actual waste is unimportant.

The manner in which the veneer is cut from the log is illustrated diagrammatically in Fig. 137; it shows how the surfaces of rotary cut veneer are approximately coincident with the annual rings, but it is not, of course, usual to obtain truly concentric ringed logs.

The rate of cutting of the veneer is dependent upon the diameter of the log, being greater for the larger diameter; the revolutions per minute are about 30, which corresponds in the case of a 3 foot diameter log with an initial cutting speed of about 280 feet per minute and a mean speed of 165 feet per minute.

* A full description is given in "The Manufacture of Veneer and Plywood," by B. C. Boulton. *Aerial Age Weekly*, 3rd Mar., 1919.

**The Surfaces of Veneer.**

The two sides of rotary cut veneer are known as the " face " and the " back," respectively; the former corresponds to the side that was convex in the log—facing outward—and the latter to the side that was concave in the log—facing towards the centre.

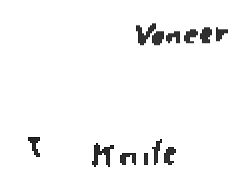



Fig. 137.

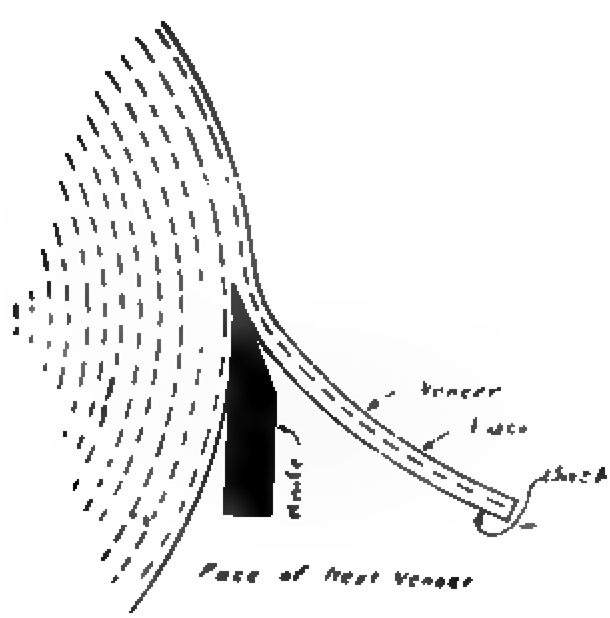



Fig. 138.

The surface of the " face " is generally the smoother, due, no doubt, to the better support which the veneer has while the face is being cut, as illustrated in Fig. 138, from which it will be seen that when the face is being cut it lies on the log's surface and is integral with it, whereas the back is unsupported except for a small portion of the knife.

The annual rings in the log are given a certain amount of reverse curvature, in the veneer, as shown in Fig. 138, but

this is not serious in the case of soft or well steamed woods, unless the thickness exceeds about $\frac{1}{8}$ to $\frac{3}{16}$ inch, when the reverse bending action produces small cracks in the surface which may extend half-way through the veneer.

These cutting cracks do not injure the veneer when it is used to form the core of plywood, since the lateral strength does not usually enter into account, and as the core is protected by the glue and the faces. In the surface veneer layers in plywood, these cracks are a detriment, and the thickness of the outside layers in the best practice are not made greater than $\frac{1}{10}$ to $\frac{1}{12}$ inch.

## Sizes of Rotary Cut Veneers.

As previously pointed out, the average length of the veneer sheets varies from 4 to 8 feet, and is, of course, governed by the length of the knife. The maximum length of veneer commercially cut is about 16 feet, but it is difficult to cut such long lengths, as the middle portion of the log is unsupported and tends to chatter and to produce irregular and cracked surfaces.

The width of veneer can be made as much as possible from the maximum to the minimum diameter of the log, provided that the cut veneer is properly handled after leaving the machine ; it is quite possible to obtain widths of from 25 to 30 feet for veneers of medium thickness.

In the case of well-steamed softwoods, veneers up to $\frac{3}{8}$ or $\frac{1}{2}$ inch can be cut, and for hardwoods such as mahogany, ash, birch, oak, or maple, from $\frac{3}{16}$ to $\frac{1}{4}$ inch is about the maximum.

Veneers from well selected special woods can be cut to a minimum thickness of about $\frac{1}{200}$ inch, but the usual thicknesses of decorative hardwood veneers vary from $\frac{1}{40}$ to $\frac{1}{64}$ inch. If the veneer is too thin, however, in the case of plywoods, or decorative veneers glued to a base-wood, the glue soaks right into the grain and spoils the surface.

For poplar and gum woods the minimum thickness is about $\frac{1}{30}$ inch.

The allowance for shrinkage from the wet width of the veneer, in order to obtain a given size, is about $1\frac{1}{2}$ inches per foot for gum, $1\frac{1}{4}$ inches for poplar, and 1 inch for oak, ash, or birch, and, roughly, 10 per cent. for other veneer woods.

**Veneer Sawing.**

This method consists in sawing thin boards, or veneer sheets, from the logs, by means of a circular saw. A special type of saw is employed, being thick in the central part and tapering on one side to a thin edge. The flat side is pushed against the log, whilst the taper on the opposite side pushes

FIG. 139.—VENEER CUTTING MACHINE OF THE ROTARY TYPE.

the veneer outward and over it, in much the same manner as is done by the knife in rotary cutting.

The log, or flitch, is securely held by numerous clamps, or dogs, which slide up and down in grooves in a fixed bracket; the latter forms a kind of carriage, which travels to and fro, carrying the log against the saw. The sheets of veneer as cut off are piled up in the order of cutting.

The length of the sheets cut off is dependent upon the travel of the carriage, and is about 20 to 25 feet in maximum cases, and about 14 to 16 feet on the average. The minimum thickness of the veneer seldom exceeds $\frac{1}{30}$ inch, and the maximum width is about 18 to 20 inches.

This process is more widely used than any other in the production of quartered veneer.

### Veneer Slicing.

In the slicing method, the log is cut by means of a knife in flat strips as in the veneer sawing method, but this process is not very much employed. Much thinner veneers can be cut by this method than by the sawing one.

In veneer slicing, the wood is sawn into blocks or flitches, which are held by means of clamps to a fixed bracket or base plate, which is given a reciprocating movement downwards and forwards, while the knife is stationary and is inclined upwards, the cutting edge being above.

The knife is fairly narrow, and rapidly increases in thickness from the cutting edge so as to provide a strong support to the same; the ordinary knife length employed is about 14 feet.

In this method there is no waste due to the saw-cut, as in the previously described process, the only waste being that due to the part of the flitch held by the dogs or clamps—usually a width of from $\frac{3}{4}$ to $1\frac{1}{8}$ inch.

The maximum length of the veneer cut depends upon the length of the knife, and seldom exceeds 16 to 18 feet; the usual size is from 12 to 14 feet.

The minimum thickness of the veneer cut varies with the nature of the wood, the harder, fine-grained woods giving the thinnest veneers. The minimum thickness for cedar or mahogany is about $\frac{1}{100}$ to $\frac{1}{120}$ inch, and the average about $\frac{1}{80}$ to $\frac{1}{90}$ inch. For soft woods it is about $\frac{1}{30}$ to $\frac{1}{50}$ inch. The maximum widths of veneer sheets cut by this method is about 20 to 24 inches.

### Grain of Veneers.

In both sliced and sawn veneers, the grain figure is usually in longitudinal narrow lines in contrast with the wide and irregular markings of rotary cut veneer. The annual rings are considerably inclined to the surfaces in these veneers, instead of being very nearly parallel as in rotary cut veneer; the

# TABLE CXLIVA

## WEIGHTS OF VENEER

In ounces per square foot of 1 ply. Veneer thickness in inches.

| *Species.* | *Sp. grav. Oven-dry based on volume Air-dry.* | *Air-dry Moisture content per cent.* | 1/100 | 1/80 | 1/64 | 1/60 | 1/55 | 1/48 | 1/40 | 1/32 | 1/28 | 1/24 | 1/20 | 1/16 | 1/12 | 1/10 | 1/8 | 1/6 | 3/16 | 1/4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ash, black .. | ·50 | 10·4 | ·42 | ·52 | ·65 | ·69 | ·76 | ·87 | 1·04 | 1·30 | 1·49 | 1·74 | 2·08 | 2·60 | 3·47 | 4·16 | 5·20 | 6·94 | 7·81 | 10·41 |
| Ash, white .. | ·64 | 8·7 | ·53 | ·67 | ·83 | ·89 | ·97 | 1·11 | 1·33 | 1·67 | 1·90 | 2·22 | 2·66 | 3·33 | 4·44 | 5·32 | 6·66 | 8·88 | 10·00 | 13·32 |
| Basswood .. .. | ·38 | 8·4 | ·32 | ·40 | ·49 | ·53 | ·58 | ·66 | ·79 | ·99 | 1·13 | 1·32 | 1·58 | 1·98 | 2·64 | 3·16 | 3·96 | 5·28 | 5·94 | 7·92 |
| Beech .. .. | ·63 | 11·2 | ·52 | ·66 | ·82 | ·87 | ·95 | 1·09 | 1·31 | 1·64 | 1·87 | 2·19 | 2·62 | 3·28 | 4·37 | 5·24 | 6·56 | 8·74 | 9·84 | 13·12 |
| Birch, yellow .. | ·63 | 9·6 | ·52 | ·66 | ·82 | ·87 | ·95 | 1·09 | 1·31 | 1·64 | 1·87 | 2·19 | 2·62 | 3·28 | 4·37 | 5·24 | 6·56 | 8·74 | 9·84 | 13·12 |
| Butternut .. | ·39 | 7·6 | ·32 | ·41 | ·51 | ·54 | ·59 | ·68 | ·81 | 1·02 | 1·16 | 1·35 | 1·62 | 2·03 | 2·71 | 3·25 | 4·06 | 5·42 | 6·09 | 8·12 |
| Cherry .. .. | ·51 | 9·2 | ·42 | ·53 | ·66 | ·71 | ·77 | ·88 | 1·06 | 1·33 | 1·52 | 1·77 | 2·12 | 2·65 | 3·54 | 4·25 | 5·31 | 7·08 | 7·97 | 10·62 |
| Cottonwood .. | ·43 | 4·7 | ·36 | ·45 | ·56 | ·60 | ·65 | ·75 | ·90 | 1·12 | 1·28 | 1·49 | 1·79 | 2·24 | 2·98 | 3·58 | 4·47 | 5·97 | 6·71 | 8·96 |
| Elm, white .. | ·51 | 8·8 | ·42 | ·53 | ·66 | ·71 | ·77 | ·88 | 1·06 | 1·33 | 1·52 | 1·77 | 2·12 | 2·65 | 3·54 | 4·25 | 5·31 | 7·08 | 7·97 | 10·62 |
| Gum, black .. | ·52 | 7·2 | ·43 | ·54 | ·68 | ·72 | ·79 | ·90 | 1·08 | 1·35 | 1·55 | 1·80 | 2·17 | 2·71 | 3·61 | 4·33 | 5·42 | 7·32 | 8·12 | 10·82 |
| Gum, cotton .. | ·52 | 6·1 | ·43 | ·54 | ·68 | ·72 | ·79 | ·90 | 1·08 | 1·35 | 1·55 | 1·80 | 2·17 | 2·71 | 3·61 | 4·33 | 5·42 | 7·32 | 8·12 | 10·82 |
| Gum, red .. .. | ·49 | 11·3 | ·41 | ·51 | ·64 | ·68 | ·74 | ·85 | 1·02 | 1·28 | 1·46 | 1·70 | 2·04 | 2·55 | 3·40 | 4·08 | 5·10 | 6·80 | 7·66 | 10·20 |
| Hackberry .. | ·54 | 9·2 | ·45 | ·56 | ·70 | ·75 | ·82 | ·94 | 1·12 | 1·40 | 1·61 | 1·87 | 2·25 | 2·81 | 3·75 | 4·49 | 5·63 | 7·50 | 8·44 | 11·24 |
| Maple, silver .. | ·48 | 8·2 | ·40 | ·50 | ·62 | ·67 | ·73 | ·83 | 1·00 | 1·25 | 1·43 | 1·67 | 2·00 | 2·50 | 3·33 | 4·00 | 5·00 | 6·66 | 7·50 | 10·00 |
| Maple, sugar .. | ·62 | 10·5 | ·52 | ·65 | ·81 | ·86 | ·94 | 1·08 | 1·29 | 1·61 | 1·85 | 2·15 | 2·58 | 3·23 | 4·30 | 5·16 | 6·46 | 8·60 | 9·69 | 12·91 |
| Oak, red .. .. | ·63 | 10·9 | ·52 | ·66 | ·82 | ·87 | ·95 | 1·09 | 1·31 | 1·64 | 1·87 | 2·19 | 2·62 | 3·26 | 4·37 | 5·24 | 6·56 | 8·74 | 9·84 | 13·13 |
| Oak, white .. | ·69 | 11·5 | ·57 | ·72 | ·90 | ·96 | 1·05 | 1·20 | 1·44 | 1·80 | 2·05 | 2·40 | 2·87 | 3·59 | 4·79 | 5·74 | 7·18 | 9·58 | 10·78 | 14·37 |
| Poplar, yellow .. | ·41 | 6·1 | ·34 | ·43 | ·53 | ·57 | ·62 | ·71 | ·85 | 1·07 | 1·22 | 1·42 | 1·71 | 2·13 | 2·84 | 3·41 | 4·27 | 5·69 | 6·40 | 8·54 |
| Sycamore .. .. | ·50 | 9·2 | ·42 | ·52 | ·65 | ·69 | ·76 | ·87 | 1·04 | 1·30 | 1·49 | 1·73 | 2·08 | 2·60 | 3·47 | 4·16 | 5·20 | 6·94 | 7·82 | 10·41 |
| Walnut, black .. | ·57 | 4·8 | ·47 | ·59 | ·74 | ·79 | ·86 | ·99 | 1·19 | 1·48 | 1·70 | 1·98 | 2·37 | 2·97 | 3·96 | 4·75 | 5·94 | 7·92 | 8·91 | 11·87 |
| Cypress .. .. | ·43 | 9·0 | ·36 | ·45 | ·56 | ·60 | ·65 | ·75 | ·90 | 1·12 | 1·28 | 1·49 | 1·79 | 2·24 | 2·98 | 3·58 | 4·47 | 5·97 | 6·72 | 8·96 |
| Fir, Douglas .. | ·44 | 9·4 | ·37 | ·46 | ·57 | ·61 | ·67 | ·76 | ·92 | 1·15 | 1·31 | 1·53 | 1·83 | 2·29 | 3·05 | 3·66 | 4·58 | 6·10 | 6·87 | 9·16 |
| Hemlock .. .. | ·42 | 8·6 | ·35 | ·44 | ·55 | ·58 | ·64 | ·73 | ·87 | 1·09 | 1·25 | 1·46 | 1·75 | 2·18 | 2·91 | 3·50 | 4·37 | 5·83 | 6·56 | 8·74 |
| Pine, longleaf .. | ·66 | 9·2 | ·55 | ·69 | ·86 | ·92 | 1·00 | 1·15 | 1·37 | 1·72 | 1·96 | 2·29 | 2·75 | 3·44 | 4·58 | 5·50 | 6·88 | 9·16 | 10·32 | 13·75 |
| Pine, sugar .. | ·37 | 11·4 | ·31 | ·39 | ·48 | ·51 | ·56 | ·64 | ·77 | ·96 | 1·10 | 1·28 | 1·54 | 1·93 | 2·57 | 3·08 | 3·85 | 5·14 | 5·78 | 7·70 |
| Pine, Western yellow | ·41 | 10·8 | ·34 | ·43 | ·53 | ·57 | ·62 | ·71 | ·85 | 1·07 | 1·22 | 1·42 | 1·71 | 2·13 | 2·84 | 3·41 | 4·27 | 5·69 | 6·40 | 8·54 |
| Pine, white .. | ·39 | 9·9 | ·33 | ·41 | ·51 | ·54 | ·59 | ·68 | ·81 | 1·02 | 1·16 | 1·35 | 1·62 | 2·03 | 2·71 | 3·25 | 4·06 | 5·42 | 6·09 | 8·12 |
| Spruce, Sitka .. | ·38 | 8·9 | ·32 | ·40 | ·49 | ·53 | ·58 | ·66 | ·79 | ·99 | 1·13 | 1·32 | 1·58 | 1·98 | 2·64 | 3·16 | 3·96 | 5·28 | 6·94 | 7·92 |
| Mahogany, African | ·46 | 5·6 | ·38 | ·48 | ·60 | ·64 | ·70 | ·80 | ·96 | 1·20 | 1·37 | 1·60 | 1·92 | 2·39 | 3·19 | 3·83 | 4·79 | 6·38 | 7·18 | 9·58 |
| Cedar, Spanish .. | ·34 | 7·3 | ·28 | ·35 | ·44 | ·47 | ·51 | ·59 | ·71 | ·88 | 1·01 | 1·18 | 1·42 | 1·77 | 2·36 | 2·83 | 3·54 | 4·72 | 5·31 | 7·08 |
| Mahogany, True (Cen. America) | ·49 | 7·9 | ·41 | ·51 | ·65 | ·68 | ·75 | ·85 | 1·02 | 1·28 | 1·46 | 1·70 | 2·04 | 2·55 | 3·50 | 4·08 | 5·10 | 6·80 | 7·66 | 10·20 |

Weight of glue per square foot: Blood Albumen about 0·3 ounce; Certus about 0·4 ounce.

inclination of these rings may vary considerably with the surface in any one strip of veneer.

In order to obtain marked grain effects, for decorative purposes, the direction of cutting the veneer is altered, and timbers, or logs, with irregular grains and branch intrusions are employed.

**Weight of Veneers.**

The weight per square foot of veneer can, of course, be readily found from the density of the timber from which it is cut.

Thus, if $w =$ weight per cubic foot in pounds,
$t =$ thickness of veneer in inches,

then weight per square foot $= \frac{wt}{12}$ pounds.

Again, if $\rho =$ specific gravity of the timber,
then weight per square foot $= 5{\cdot}208\ \rho.t.w.$

Table CXLIVA* gives the weights of veneers of different thicknesses, in inches, expressed in ounces per square foot.

Some data, derived from the author's investigations on veneer fabric coverings for aeronautical work, is given in Table CXLV.

## PLYWOODS

Plywoods consist of a number of layers of veneer, of the same, or of different kinds of timbers, glued together so that their grains run at different angles.

The principal advantages of this arrangement are: (1) That the material may be made of approximately equal shear, tensile, and compressive strength in all directions; and (2) that the resulting boards or plywoods do not warp appreciably, compared with solid boards.

It is well known that the tensile strength of a wood along the grain is about seventeen times the strength across the grain, taking the average of a large number of dry woods;

* The Forest Products Laboratory of Bureau of Aircraft Production, America, 1919.

if, now, two layers or veneers of the same wood be glued at right angles, then the tensile strength in any direction will be one-half of the value for the single layer along the grain, and 8½ times the cross-tensile strength.

In this way it is possible to obtain a homogeneous material of equal strength in all superficial directions, which is of very great value for a large amount of constructional purposes.

Table CXLVI* shows the mechanical strength properties of various plywoods, of the three-ply type, with the grain of successive plies at right angles. All of the plies in any one panel were of the same thickness and of the same species, and eight thicknesses of plywood ranging from $\frac{3}{50}$ to $\frac{3}{8}$ inch were tested.

The same table shows the specific gravity of the plywood for the indicated average moisture content.

## TABLE CXLV.

### Weights of Veneer Fabric Coverings.

| *Material.* | *Thickness, millimetres.* | *Weight per square yard (ounces).* |
|---|---|---|
| Satin-walnut with 1 layer aero. fabric glued on one side .. .. .. .. .. | 1·0 | 18·9 |
| Satin walnut with 2 layers aero. fabric glued one each side .. .. .. .. | 1·10 | 23·6 |
| Red cedar with 2 layers aero. fabric glued one each side .. .. .. .. | 0·60 | 14·4 |
| Red cedar, 2-ply with fabric glued on each side | 1·50 | 30·7 |
| Silver spruce veneer with 1 layer aero. fabric, glued .. .. .. .. .. | 1·75 | 29·3 |
| English aspen veneer with 1 layer aero. fabric, glued .. .. .. .. .. | 1·00 | 15·8 |
| Horse chestnut veneer with 1 layer aero fabric, glued .. .. .. .. .. | 0·75 | 14·04 |
| Horse chestnut veneer with 2 layers aero. fabric glued, one each side .. .. .. | 0·85 | 18·00 |
| Horse chestnut veneer with 2 layers and 4 coats of dope .. .. .. .. | 0·95 | 22·00 |
| Yellow pine veneer with 1 layer aero fabric glued .. .. .. .. .. | 1·45 | 21·00 |

* Forest Products Laboratory Data, compiled by B. C. Boulton. *Vide* "The General Properties and Uses of Plywoods," *Aerial Age Weekly*, 21st July, 1919.

# TABLE CXLVI.

## TABLE OF STRENGTHS OF VARIOUS SPECIES OF 3-PLY PANELS

All plywood was 3-ply with the grain of successive plies at right angles.
All plies in any one panel were of the same thickness and of the same species. Eight thicknesses of plywood ranging from 3/30 in. to 3/16 in. were tested.

| Species. | Average specific gravity of Plywood† | Average per cent. Moisture. | Column Bending Modulus. | | | | Tensile Strength. | | | | Split Resistance. | | Modulus of Elasticity. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Parallel. | | *Perpendic'r. | | *Parallel. | | *Perpendic'r. | | | | *Parallel. | *Perpend. |
| | | | No. of Tests | Pounds per sq. inch | No. of Tests | Pounds per sq. inch | No. of Tests | Pounds per sq. inch | No. of Tests | Pounds per sq. inch | No. of Tests. | Per cent. of birch resistance. | Pounds per sq. inch in bending. | Pounds per sq. inch in bending |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Birch, yellow .. | ·67 | 8·5 | 195 | 16000 | 200 | 3200 | 200 | 13200 | 200 | 7700 | 400 | 100 | 2259000 | 197000 |
| Ash, black .. .. | ·48 | 9·2 | 80 | 7360 | 80 | 1620 | 80 | 6200 | 80 | 3940 | 160 | 68 | 1028000 | 87000 |
| Ash, commercial white | ·61 | 10·6 | 160 | 9980 | 160 | 2640 | 160 | 6540 | 160 | 4330 | 320 | 72 | 1422000 | 144000 |
| Basswood .. .. | ·41 | 9·6 | 160 | 6520 | 160 | 1540 | 160 | 6300 | 160 | 4100 | 320 | 65 | 1213000 | 85000 |
| Beech .. .. | ·67 | 8·6 | 120 | 15390 | 120 | 2950 | 120 | 13000 | 120 | 7260 | 240 | 76 | 2149000 | 167000 |
| Cedar, Spanish .. | ·41 | 13·3 | 115 | 6460 | 115 | 1480 | 115 | 5200 | 115 | 3340 | 230 | 60 | 1032000 | 84000 |
| Cherry .. .. | ·49 | 9·9 | 40 | 11180 | 40 | 2220 | 40 | 6920 | 40 | 5650 | 80 | 86 | 1448000 | 150000 |
| Chestnut .. .. | ·43 | 11·7 | 40 | 5160 | 40 | 1110 | 40 | 4430 | 40 | 2600 | 80 | 74 | 744300 | 75000 |
| Cottonwood .. .. | ·48 | 9·5 | 40 | 8110 | 40 | 1660 | 40 | 7540 | 40 | 4500 | 80 | 94 | 1461000 | 110000 |
| Fir, Douglas .. | ·45 | 8·4 | 105 | 8890 | 110 | 1730 | 110 | 5630 | 110 | 8530 | 220 | 59 | 1316000 | 129000 |
| Elm, cork .. .. | ·59 | 11·7 | 35 | 10530 | 35 | 2160 | 35 | 9840 | 35 | 6040 | 70 | 100 | 1729000 | 125000 |
| Elm, white .. .. | ·53 | 8·9 | 120 | 8810 | 120 | 1990 | 120 | 6460 | 120 | 4190 | 240 | 85 | 1230000 | 112000 |
| Gum, red .. .. | ·54 | 8·5 | 102 | 9330 | 102 | 1830 | 102 | 7780 | 102 | 4890 | 204 | 68 | 1487000 | 107000 |
| Gum, cotton .. | ·49 | 10·3 | 80 | 7770 | 80 | 1580 | 80 | 6260 | 80 | 3770 | 160 | 60 | 1300000 | 111000 |
| Gum, black .. .. | ·54 | 10·6 | 40 | 8090 | 40 | 1920 | 35 | 6960 | 35 | 4320 | 70 | 55 | 1275000 | 113000 |
| Hackberry .. .. | ·54 | 10·9 | 40 | 8380 | 40 | 1720 | 40 | 7870 | 40 | 4550 | 80 | 85 | 1257000 | 111000 |
| Hemlock .. .. | ·49 | 9·2 | 40 | 9520 | 40 | 2120 | 40 | 7490 | 40 | 4740 | 80 | 65 | 1614000 | 120000 |
| Maple, soft .. .. | ·60 | 9·0 | 80 | 11750 | 80 | 2430 | 80 | 8020 | 80 | 5470 | 160 | 114 | 1822000 | 147000 |
| Maple, hard .. | ·68 | 7·6 | 82 | 15870 | 82 | 3320 | 82 | 11610 | 82 | 7060 | 164 | 124 | 2009000 | 186000 |
| Mahogany, true .. | ·48 | 11·4 | 35 | 8500 | 35 | 1940 | 35 | 6390 | 35 | 3780 | — | — | 1252000 | 117000 |
| Mahogany, African.. | ·52 | 12·7 | 20 | 8070 | 20 | 2000 | 20 | 5370 | 20 | 3770 | — | — | 1261000 | 144000 |
| Mahogany, Philippine | ·53 | 10·7 | 25 | 10160 | 25 | 2310 | 25 | 10670 | 25 | 5990 | 50 | 90 | 1820000 | 169000 |
| Mangolia .. .. | ·59 | 9·9 | 40 | 9830 | 40 | 2340 | 40 | 10000 | 40 | 5740 | 80 | 98 | 1704000 | 135000 |
| Oak, white .. .. | ·64 | 10·1 | 75 | 9440 | 75 | 1920 | 75 | 7260 | 75 | 3950 | 150 | 90 | 1085000 | 106000 |
| Oak, red .. .. | ·59 | 9·3 | 115 | 8500 | 115 | 2070 | 115 | 5480 | 115 | 3610 | 230 | 80 | 1289000 | 120000 |
| Pine, white .. .. | ·43 | 10·2 | 35 | 7920 | 40 | 1770 | 40 | 5640 | 40 | 3870 | 80 | 52 | 1274000 | 99000 |
| Poplar, yellow .. | ·50 | 9·0 | 120 | 8900 | 120 | 1920 | 110 | 7380 | 120 | 4520 | 240 | 52 | 1501000 | 114000 |
| Redwood .. .. | ·41 | 11·2 | 65 | 7900 | 65 | 1500 | 65 | 5100 | 65 | 3000 | 130 | 48 | 1211000 | 118000 |
| Sycamore .. .. | ·56 | 10·0 | 80 | 10920 | 80 | 2390 | 80 | 8840 | 80 | 5480 | 160 | 79 | 1642000 | 135000 |
| Spruce, Sitka .. | ·41 | 8·0 | 63 | 7280 | 63 | 1540 | 63 | 5180 | 63 | 3150 | 126 | 75 | 1176000 | 98000 |
| Walnut, black .. | ·58 | 9·7 | 80 | 11850 | 80 | 2660 | 80 | 7640 | 80 | 5100 | 160 | 77 | 1664000 | 144000 |

* Parallel and perpendicular refer to the direction of the grain of the faces relative to the direction of the application of the force.
† Specific gravity based on oven dry weight and volume at test.

Table CXLVII gives the tensile strength of 3-ply woods parallel to the grain of the faces, and also that of the single ply veneer of the corresponding same materials taken as being 50 per cent. greater than that of the plywood on the assumption that the centre ply carries no load.

TABLE CXLVII.

TENSILE STRENGTH OF PLYWOOD AND VENEER.

| *Species.* | *No. of tests.* | *Moisture at Test Per cent.* | **Specific gravity of plywood.* | *† Tensile strength of 3-ply wood parallel to grain of faces. Pounds per square inch.* | *‡ Tensile strength of single ply veneer—1½ (d) Pounds per square inch.* |
|---|---|---|---|---|---|
| | (a) | (b) | (c) | (d) | (e) |
| Birch .. .. .. | 200 | 8·5 | ·67 | 13240 | 19860 |
| Ash, black .. .. | 80 | 9·1 | ·57 | 6200 | 9300 |
| Ash, commercial white | 120 | 10·5 | ·61 | 6700 | 10050 |
| Basswood .. .. | 160 | 9·6 | ·41 | 6300 | 9450 |
| Beech .. .. | 120 | 8·6 | ·67 | 13000 | 19500 |
| Cedar, Spanish .. | 80 | 11·8 | ·43 | 5220 | 7830 |
| Cherry .. .. | 40 | 9·9 | ·49 | 6920 | 10380 |
| Chestnut .. .. | 40 | 11·7 | ·43 | 4430 | 6640 |
| Cottonwood .. .. | 40 | 9·5 | ·48 | 7540 | 11310 |
| Douglas fir .. .. | 110 | 8·4 | ·45 | 5630 | 8440 |
| Elm, cork .. .. | 35 | 11·7 | ·59 | 9840 | 14760 |
| Elm, white .. .. | 120 | 8·9 | ·53 | 6460 | 9690 |
| Gum, red .. .. | 102 | 8·5 | ·54 | 7780 | 11670 |
| Gum, cotton .. .. | 80 | 10·3 | ·49 | 6260 | 9390 |
| Maple, soft .. .. | 80 | 9·0 | ·60 | 8020 | 12030 |
| Maple, sugar .. .. | 82 | 7·6 | ·68 | 11610 | 17420 |
| Oak, red .. .. | 115 | 9·3 | ·59 | 5480 | 8220 |
| Oak, white .. .. | 75 | 10·1 | ·64 | 7260 | 10890 |
| Poplar, yellow .. | 80 | 8·8 | ·50 | 7130 | 10690 |
| Redwood .. .. | 65 | 11·2 | ·41 | 5100 | 7650 |
| Sycamore .. .. | 40 | 10·2 | ·56 | 9180 | 13770 |
| Spruce, Sitka .. .. | 40 | 7·9 | ·41 | 4900 | 7350 |
| Walnut, black .. | 80 | 9·7 | ·58 | 7640 | 11460 |
| Pine, white .. .. | 40 | 10·2 | ·43 | 5640 | 8460 |
| Mahogany, Philippine | 25 | 10·7 | ·53 | 10670 | 16000 |
| Mahogany, true .. | 35 | 11·4 | ·47 | 6380 | 9570 |
| Mahogany, African .. | 20 | 12·7 | ·52 | 5370 | 8060 |

## Timbers Used in Plywoods.

There is a fairly large number of woods available for making plywood, depending upon the purpose for which the latter is required.

Woods that are most used for plywood manufacture comprise oak, ash, birch, maple, mahogany, walnut, red gum,

* Specific gravity based on oven dry weight and volume at test.

† Based on total cross sectional area.

‡ Based on assumption that centre ply carries no load. Data based on tests of three-ply panels withall plies in any one panel same thickness and species.

etc., for the faces, and poplar, bass-wood, aspen, spruce, pine, etc., for the cores.

For aeroplane constructional work,* such as for wing-ribs, formers, panels, flooring, etc., it is usual to specify† a plywood in which the outer layers are of birch or ash and the central layer, which is from $\frac{1}{2}$ to $\frac{3}{5}$ of the total thickness, of aspen or American whitewood ; the grains of the outer layers should be parallel and run in the direction of the length of the plywood sheet, whilst that of the inner core should be at right angles to the outer grains.

The wood selected by a very large American plywood manufacturing company‡ is the red gum (*liquidambar styraciflua*), as it appears to possess better general properties than any other wood examined.

This wood is only about three-quarters of the weight of most native woods used for the faces of plywood, and its face hardness is ample for the outer layers, whilst the lateral strength is such that this wood is satisfactory for the core, or central layer ; the same material is therefore used throughout.

Red gum has a very uniform texture ; the annual rings are not distinct because there is little difference between the summer and spring woods. This uniformity of structure has two effects, namely, that it cuts into veneer uniformly, and without reference as to whether the knife-edge is in summer or spring wood, and the veneers are of uniform properties for both summer and spring woods.

Although the annual rings of red gum are indistinct, a large proportion of the veneer that is cut from this wood shows particularly interesting and characteristic markings, so that it can be used for decorative purposes ; for this reason it is used under trade names of "satin walnut," "hazel," and "Circassian walnut."

* See also "Data on the Design of Plywood for Aircraft," Report No. 84, U.S. National Advisory Committe for Aeronautics, 1920.

† See p. 519.

‡ The Haskelite Manufacturing Corporation, Chicago, to whom the Author is indebted for information and data concerning their products.

Red gum is straight grained and possesses very good strength and elastic properties.

The following are the properties of this wood,* and also of *yellow poplar*, both of which are given at 10 per cent. moisture.

## TABLE CXLVIII.

PROPERTIES OF RED GUM AND YELLOW POPLAR.

| *Property.* | *Red Gum.* | *Yellow Poplar.* |
|---|---|---|
| Number of annual rings per inch .. .. | 16 | 14 |
| Weight per cubic foot (12 per cent. moisture) pounds | 34 | 27 |
| Elastic limit (static bending), pounds per square inch | 9060 | 6810 |
| Modulus of rupture (static bending), pounds per square inch .. .. .. .. .. | 12900 | 10200 |
| Modulus of elasticity (static bending), pounds per square inch .. .. .. .. .. | 1540000 | 1490000 |
| Work done up to elastic limit (static bending), inch pounds per cubic inch .. .. .. .. | 3·74 | 1·92 |
| Work done up to maximum load (static bending), inch pounds per cubic inch .. .. .. | 11·6 | 7·8 |
| Elastic limit in impact bending, pounds per square inch .. .. .. .. .. .. | 20300 | 16100 |
| Work done up to elastic limit (impact bending), inch pounds per cubic inch .. .. .. | 11·1 | 7·5 |
| Impact bending, height of drop to failure .. | 31·1 | 26 |
| Compression parallel to grain (elastic limit), pounds per square inch .. .. .. .. | 5280 | 3740 |
| Compression parallel to grain (maximum strength) pounds per square inch .. .. .. | 6330 | 6470 |
| Compression perpendicular to grain (elastic limit), pounds per square inch .. .. .. | 850 | 600 |
| Shearing strength parallel to grain, pounds per square inch .. .. .. .. .. | 1840 | 1010 |
| Tensile strength perpendicular to grain, pounds per square inch .. .. .. .. .. | 880 | 550 |
| Tensile strength parallel to grain, pounds per square inch .. .. .. .. .. | 11220 | — |
| End hardness .. .. .. .. .. | 1050 | 530 |
| Side hardness .. .. .. .. .. | 730 | 430 |

### Manufacture of Plywood.†

The veneers used for plywood are first dried, as in many cases they have been cut from a steamed log; the drying

* Bulletin No. 556, U.S. Dept. of Agriculture.
† The method outlined is that adopted by the Haskelite Co.

process to a moisture content of about 10 per cent. also leaves the veneer flat.

The veneer as it is received contains numerous defects that were present in the log or have resulted from bad cutting. These defects are avoided by cutting the veneer sheets with large shears, or clippers, which trim each piece to a width that is free from defects, and to certain convenient standard sizes.

The various veneers are next sorted out to suit the different plies of the plywood to be made, and one piece will generally have to be cut to a narrower width to make the proper total width of ply.

The face plies now go to the taping machine, which connects adjacent plies by means of a strip of thin paper tape that is glued to the face of each in such a way that the edges are brought into contact. This assembles each ply into its full size form.

It is important, in the manufacture of plywood, to avoid shrinkage, as the resulting material is otherwise left in a state of stress. In the case of rotary cut veneer the shrinkage is about 10 per cent. in a transverse direction across the grain, from the green to the dry condition. If the plies of a panel are moist when they are glued together, and are dried later as a glued-up panel, each ply will endeavour to shrink across its grain; this action will, however, be prevented by the plies that have their grain running in an opposite direction, so that the net result of this shrinkage tendency is that a tensile stress is set up in the ply that would shrink, and a compressive stress in the ply resisting the shrinkage. The tensile stress is across the grain of the ply in which it occurs, whilst the compressive stress is along the grain of the ply in which it is located.

In best practice, these manufacturing stresses are avoided by drying the core plies after their faces have been coated with glue, but the glue is not set by this drying process. After this is done, fresh glue is spread on the backs of the two-face plies that form a single panel, and, without any

great delay, these plies are placed above and below the core, and the plies so assembled are at once placed in the press to be glued together.

The whole of the veneers are very dry just before the glue is spread upon the ply faces. The time between this spreading of the glue and the pressing operation is fairly short, so that each ply has not much time to absorb moisture. Since each ply is comparatively dry when it is placed in the press, it will not tend to shrink appreciably across the grain and produce the initial stresses which frequently occur in the ordinary methods of gluing. The moisture in the glue spread on the face plies soaks up the dried glue on the core and makes it have the right consistency for setting under the action of the press to form a good waterproof joint.

Just before the face plies are taken to the spreaders to receive the coating of glue on their backs, their joints are opened, and the edges of the veneers are coated with glue, which is set in the press at the same time that the glue is set that connects the plies together. Although the face ply may be made up of several strips of veneer, they are thus securely glued together into a single piece independent of the fact that they are also glued to the core of the panel.

The glue used in plywood manufacture is usually a casein,* or a special blood-albumen glue, which, when once properly set, gives a joint insoluble in cold or warm water, and very strong in shear and tension.

The gluing press consists of cast-iron plates with flat faces, which are heated to about 210° F. by means of steam circulated through the interior of each plate. The plies that are to be glued are placed between two of these plates, and the plates are then forced together by hydraulic pressure adjusted to the size of the panels being glued and to the pressure required per square inch of its surface. The heat from these plates penetrates the face plies and sets the glue while the surfaces are thus closely pressed together.

* Such as "Certus" glue.

The panels, when they come from the press, are usually about 2 inches wider and 2 inches longer than the dimensions required for the finished sizes.

## AIR MINISTRY TEST SPECIFICATIONS FOR THREE-PLY.

It is usual to specify the following test on plywood required for aircraft construction purposes.

(*a*) MOISTURE CONTENT.—A small specimen of the plywood, about 2 inches square, is to be placed in an oven at 105° C. for a period of 10 hours; the loss of weight at the end of this period must not exceed 15 per cent.

(*b*) SHEARING TEST.—It is specified that the cement joints between the layers, or veneers, are to be stronger than the wood itself. For this test at least three pieces of plywood of the dimensions shown in Fig. 140 must be cut from each batch under examination. The plywood

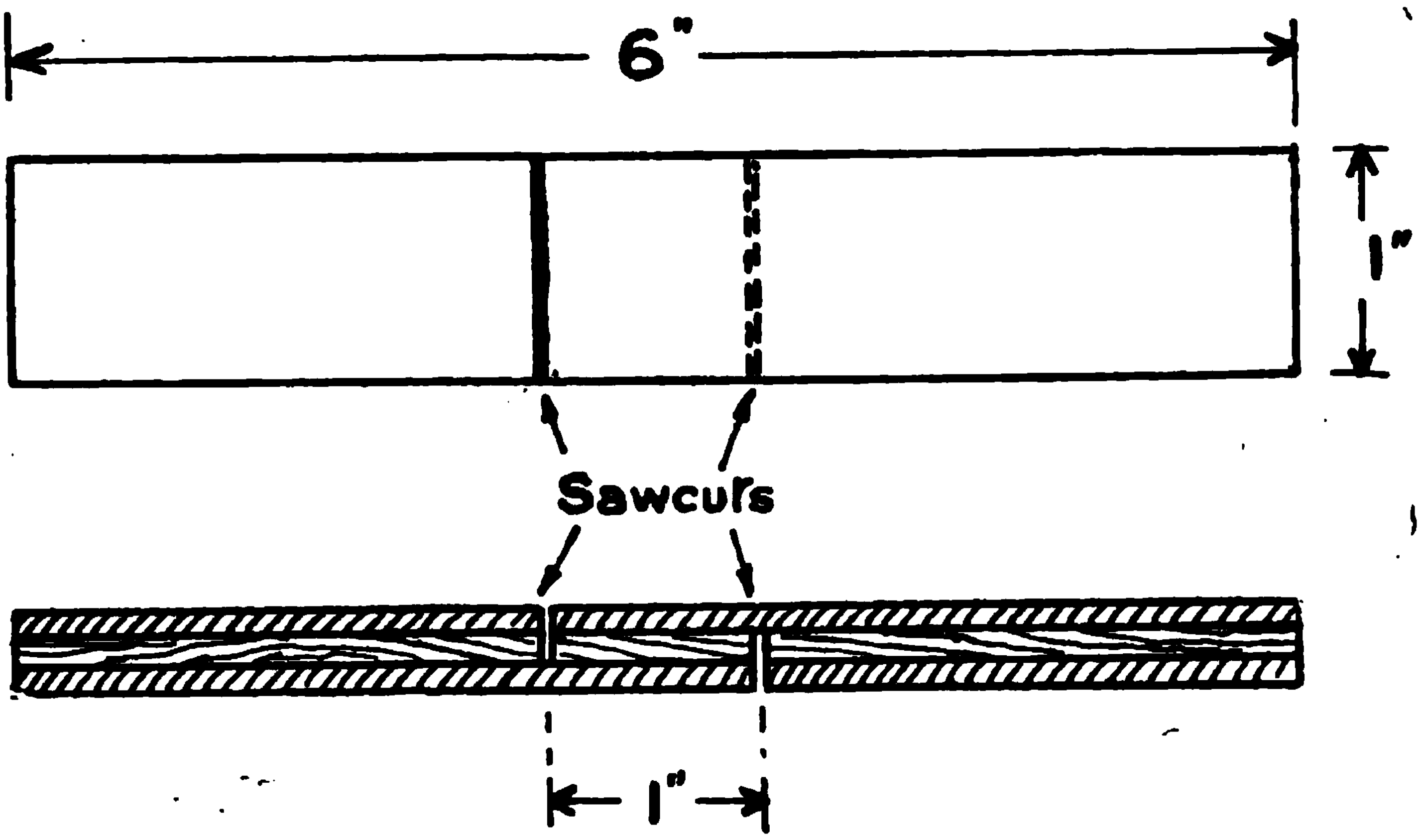



FIG. 140.—THREE-PLY TEST SPECIMEN.

is then saw-cut in two places 1 inch apart, as shown in the diagram. The specimen is then tested in tension, and the failing stress of two out of three specimens should be at least 150 pounds per square inch. (It will be seen that the effect of a tension load is to shear the cement joints.)

(*c*) ABSORPTION TESTS.—This test is stipulated with the object of ensuring that the plywood does not absorb too much moisture and that the veneers do not part. A test piece 6 inches square is immersed in water at a temperature of 45° C. for a period of 3 hours in the case of veneers of thickness up to $\frac{1}{30}$ inch, and for 6 hours in the case of thicker veneers. At the end of this period there should be no visible separation of the veneers.

(*d*) BENDING TEST.—The following tests are specified for plywoods of $\frac{1}{8}$ inch thickness and less: A specimen 12 inches by 2 inches is cut

so that the grain of the outer plies is running across the length of the strip. The specimen is bent on the rim of a former 18 inches in diameter, first one way and then the other. No sign of splitting, fracture, or separation of the veneers should be visible after this test.

## Panels for Automobile Work.

Automobile roof panels average about 56 inches wide by 96 inches long. Since the length of most strips of veneer is shorter than the length of such a panel, it is generally necessary to scarf the strips of veneer (as shown in Fig. 141) that are put into the panel, with their grain parallel to its length. This is done before the panel is glued up.

In scarfing, two strips of veneer of the same thickness and width are selected. On one end of each strip a long taper is made on a special machine, as shown in Fig. 141 ; the tip

FIG. 141.

of the taper is on the face of one strip and on the back of the other. Glue is spread on the taper of each strip; the tapers are properly lapped and placed in a small steam-heated press, which forces the strips together, and the glue is set by the heat, as in the larger presses.

## Sizes of Plywoods.

The most common thickness of plywood employed for automobile panels is about $\frac{5}{16}$ inch, but thicknesses of $\frac{1}{4}$ and $\frac{3}{8}$ inch are employed to some extent.

The sizes of the cores for $\frac{1}{4}$, $\frac{5}{16}$, and $\frac{3}{8}$ inch Haskelite plywood are $\frac{1}{8}$, $\frac{3}{16}$, and $\frac{1}{4}$ inch respectively. For each of these panels the face veneer used is $\frac{1}{32}$ inch thick if the panel is to be "machine sanded," while the faces are made of $\frac{1}{16}$ inch veneer if but little sanding is to be done. When the faces are initially but $\frac{1}{16}$ inch thick, the finished panel may be a few thousandths of an inch thinner than the specified thickness,

due probably to a small amount of compression in the gluing press and to sanding.

The number of layers or plies used may be either 2, 3, or 5, and in special cases a considerably greater number of plies is used.

The thickness of the veneer in either three or five ply construction is usually about $\frac{1}{32}$ inch for each ply, when used for aircraft work.

The sizes of the sheets vary according to the purpose for which they are required, a common English size being 8 feet long by 2 feet wide, and American size, 8 feet by 4 feet 6 inches, but special sizes are made up for any particular purpose.

### Strength of Haskelite Plywood.

This plywood is composed of an inner core of red gum veneer and two face plies of the same wood. The tensile strength along the grain is about 11,220 pounds per square inch, and across the grain, 900 pounds per square inch. The core strength is neglected, however.

The following are the strength and weight properties of this plywood—

TABLE CXLIX.

| *Property.* | *Thickness.* | | |
|---|---|---|---|
| | $\frac{1}{4}$ | $\frac{5}{16}$ | $\frac{3}{8}$ |
| Tensile strength parallel to face grain, pounds per square inch .. .. | 5600 | 4480 | 3730 |
| Tensile strength parallel to face grain, pounds per inch width .. .. | 1400 | 1400 | 1400 |
| Tensile strength parallel to core grain, pounds per square inch .. .. | 5600 | 6720 | 7470 |
| Tensile strength parallel to core grain, pounds per inch width .. .. | 1400 | 2100 | 2800 |
| Weight in pounds per 100 square feet | 75 | 93 | 111 |
| Moment of inertia for 1 inch wide strips | | | |
| (Section) Perpendicular to face grain (inches)$^4$ .. .. .. .. | ·00114 | ·00197 | ·00310 |
| (Section) perpendicular to core grain (inches)$^4$ .. .. .. .. | ·00016 | ·00055 | ·00130 |

**Consuta Plywood.**

This is a patented method* of making ply-wood, in which the veneers are not only glued or cemented together, but are also sewn through with rows of parallel stitching, so that a very strong material is obtained, in which the layers are strongly held together, and tensile stresses are resisted by the stitching in addition to the glue.

This method of making plywood has been widely used in the construction of very fast motor boats, launches, and service boats ; it is also employed for the gondolas of airships, and the hulls and floats of flying boats and seaplanes.

The veneers were formerly sewn together by hand, but are now machine-stitched, so that the plywood can be produced in large quantities for commercial purposes.

The average spacing of the rows of stitches in the case of $\frac{3}{16}$ inch plywood is $1\frac{1}{4}$ inches, and the pitch of the stitches is $\frac{1}{4}$ inch ; the stitches can be sunk flush with the surface, or left above, as desired.

In general, the laminae are specially laid in the direction most suitable for the particular object in view. For example, when Consuta is used for the sides of a boat, the fuselage sides, or the covering of a wing, the grain would be laid in reverse diagonals, giving a girder type of construction.

This material is practically impervious to all atmospheric conditions, as the glue is waterproof and the stitches hold the laminae rigidly together ; the wood surfaces are further coated with paint or varnish so that the wood pores are sealed.

Consuta is made principally in cedar and mahogany, and is obtainable in sheets up to 8 feet wide and 60 feet long, and in thicknesses of $\frac{1}{8}$ to $\frac{5}{8}$ inch.

A typical example of Consuta plywood construction is in the case of the Vickers' commercial aeroplane fuselage.

**Beaver Board.**

This material is made from selected woods, usually spruce, reduced to the fibrous form and compressed into panels of

* S. E. Saunders, Cowes.

uniform thickness. The sizes of the panel vary from 3 to 4 feet wide and from 8 to 16 feet long, the thickness being $\frac{3}{16}$ inch as a rule.

The surfaces of the panels thus formed are rendered waterproof by double-sizing or similar means.

This material is a non-conductor of heat, and is partially sound-proof.

It is light in weight (that is, about 0·5 pound per square foot).

These boards are now widely used for building purposes for walls, panels, ceilings, and for various other purposes where a rigid non-warping wood material is required.

## Compressed Spruce.

Compressed spruce, made from laminations originally $\frac{3}{8}$ inch thick, compressed to 100 tons per square foot, is now being used for various engineering purposes, such as pulleys, and parts requiring great strength.

Waste spruce cuttings may be utilized in this process.*

## Applications of Plywood.

Plywoods are now fairly widely used, on account of their uniform superficial strength properties, their resistance to splitting, non-warping qualities, and general convenience.

In automobile work, plywoods have been used for replacing sheet-metal panels, for floor-boards, lockers, dash boards, body panels, etc.

In aircraft work, plywoods find a large application, as they give a high strength-to-weight ratio and are convenient to work upon.

The former and compression ribs of the wings and control planes of aircraft are generally made of three-ply wood of from $\frac{1}{8}$ to $\frac{1}{4}$ inch thickness. Ash or birch ply, with cottonwood or whitewood core, is generally preferred for these parts, and it is usual to design the ribs so that the plywood (which is

* Composite planks are now made from waste pieces, by means of a machine, such as the Lindeman one, which grooves and glues the pieces into one continuous board; these boards are much used in America for automobile body-work.

suitably lightened) forms the webs, with spruce flanges at the top and bottom; a few typical examples are shown illustrated in Fig. 142.

The engine bearers of aircraft are usually made of multiple plywood members, suitably designed. Fig. 143 shows a typical structure of this kind; the longitudinal bearers are made of ash, and the engine bolts down directly on to these members. In the case of a 300 H.P. biplane, the thickness

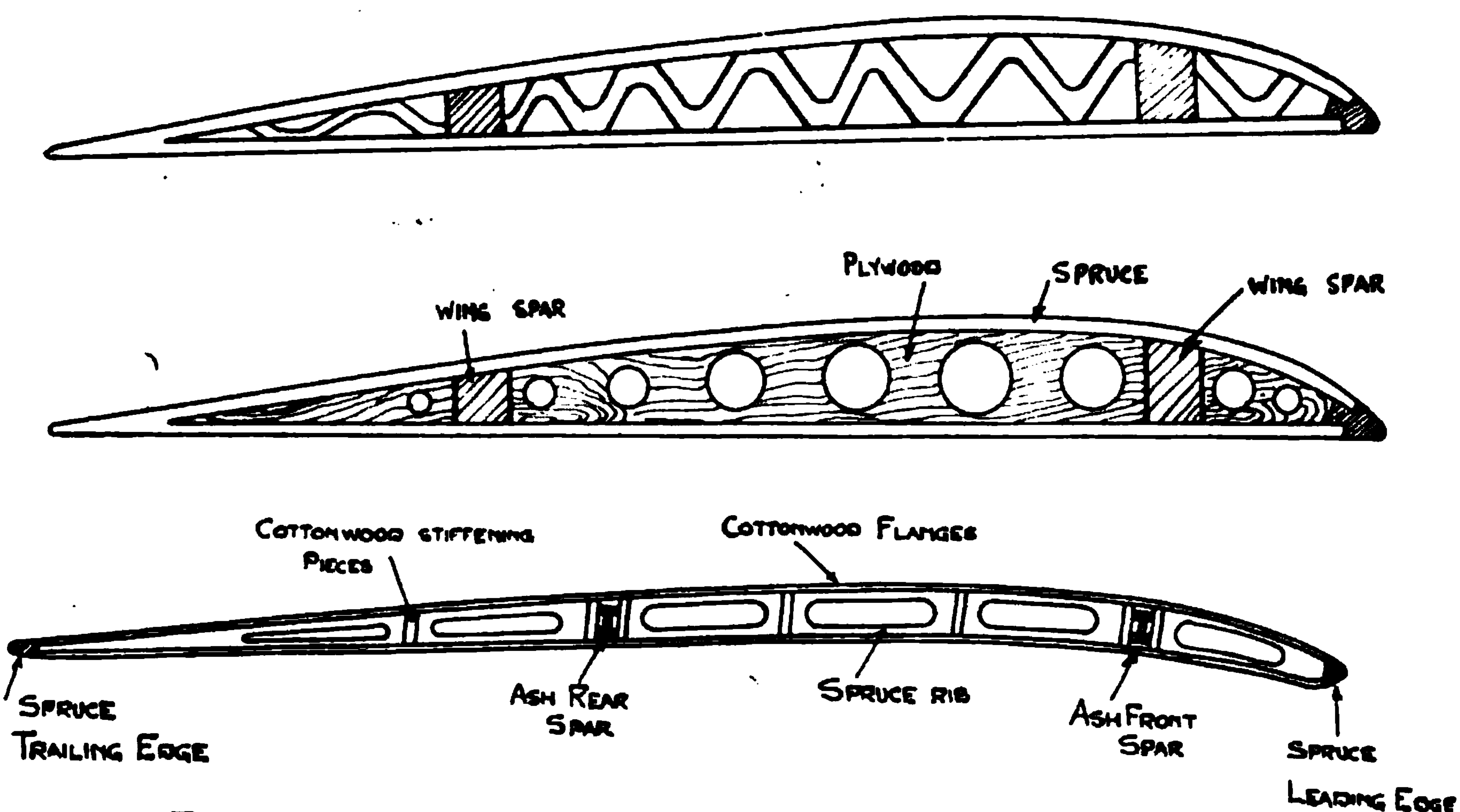



FIG. 142.—APPLICATION OF PLYWOOD TO AEROPLANE WING RIBS.

of the transverse plywood members would be about 0·7 to 1·0 inch, and there would be about 8 to 10 layers of plywood.

The instrument boards, lockers, ammunition and map boxes, floor-boards, etc., are generally made of plywoods.

Another interesting example of the use of veneers and plywoods, which has found increasing favour for all types of aircraft, is that of fuselage construction. With this rational method of making the fuselage, great strength can be combined with lightness, and cross-bracing wires which, in the girder type of fuselage construction, offer much obstruction and inconvenience, can be dispensed with, thus leaving a hollow structure very adaptable for commercial machines.

SECTION OF ENGINE BEARER.

FIG 143.—AEROPLANE ENGINE BEARERS AND STIFFENERS.

The method of construction of the early Deperdussin monocoque fuselages was, briefly, as follows—

Formers of the correct shapes of the inside of the top and bottom halves of the required body were first constructed, and over each of these formers were laid thin strips of tulip wood to form a kind of veneered surface, the object of the thin strips being to accommodate themselves to the curvature of the former without buckling, or curling, as would result if a single sheet were employed.

Three layers of wood were built up in this manner, the two strips of the first two layers running at right-angles to each other. When the cementing compound between the two layers was set, two layers of strong fabric were glued to the outside of the shell, and one layer of fabric to the inside, with the object of preventing splitting of the wood and of protecting it from external influences.

The two half-shells thus made were then connected together so as to form one complete shell, and the wings, tail unit, engine plate, and undercarriage were fastened to this shell. The thickness of the resulting shell was between 3 millimetres and 4 millimetres. This mode of construction gave a remarkably light and strong fuselage. Fig. 144 shows an outside view of the Deperdussin monocoque fuselage.

The above method of construction is not now employed, for reasons connected with economy of time and the special workmanship required.

In modern plywood fuselage construction it is usual to employ four or six longerons and a number of light frames covered with thin sheet plywood. These transverse frames are usually built up of, or cut out of plywood, and their outside shape gives the correct section to the body at that place.

Such a fuselage is superior to the ordinary wood and wire trussed framing,* as it is not only permanent in form but will withstand a great deal of perforation from projectiles such as are used in aerial fighting. This construction

* See "Fuselage Design," Messrs. Selwyn & Co., London.

corresponds closely to that of marine design, the differences appearing principally in the reduction in weight, in character of material, and in the streamline form.

Figs. 145 and 146 illustrate the principles of the method of fuselage construction previously mentioned. The former diagram shows to scale an actual fuselage design, embodying

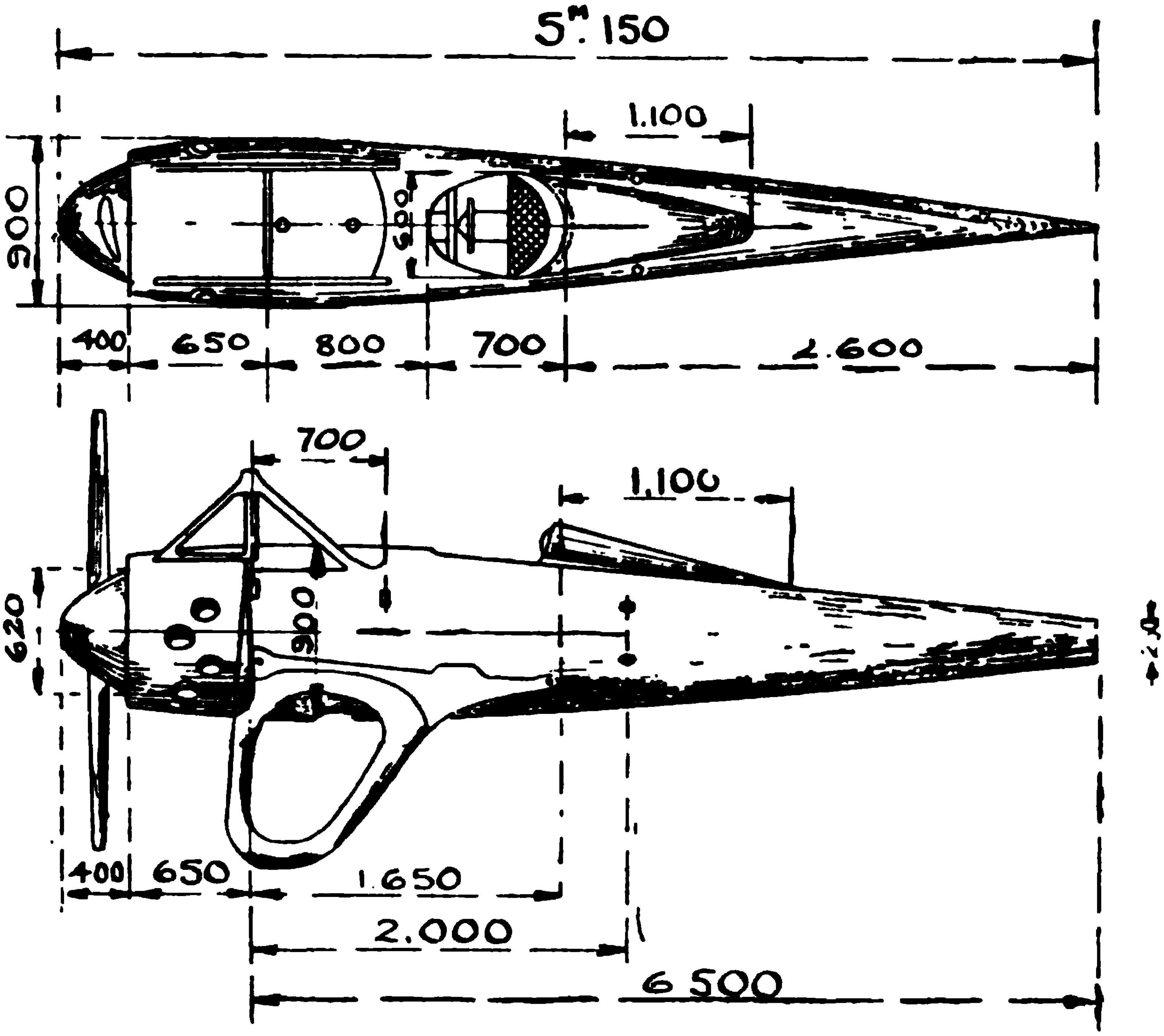



FIG. 144.—EXAMPLE OF PLYWOOD MONOCOQUE TYPE FUSELAGE.

the method of longerons, transverse sections, and plywood covering; the sections of the longerons, which are six in number, at different places along the fuselage, are shown. It will be observed that the longerons taper down in section towards the tail, and are made hollow, or spindled out, except in the parts where additional strength is required.

The fairing blocks, such as those shown in diagrams *A*,

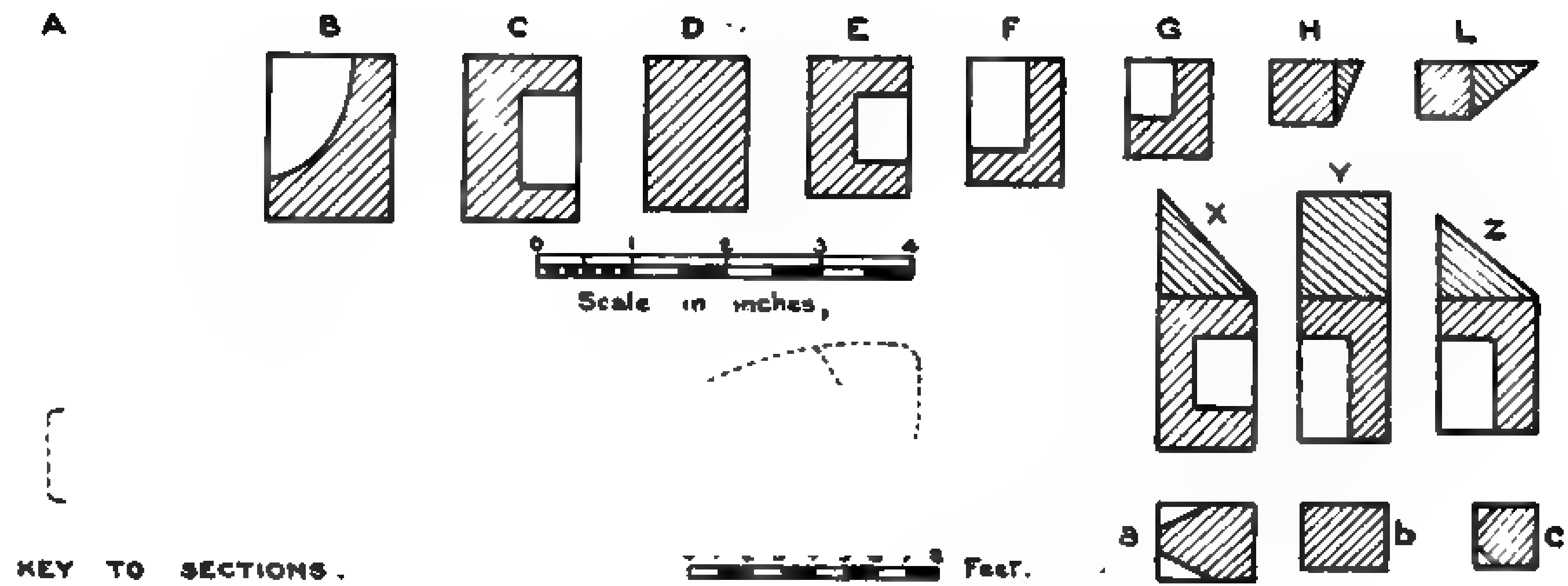



FIG. 145.—EXAMPLE OF PLYWOOD FUSELAGE DESIGN.

$H$, $L$, $X$, and $Z$ are arranged to conform to the general section shape.

The shapes of these sections at the places indicated in the outline key diagram are shown in Fig. 146.

By the aid of these two figures, the methods and the details of construction can be readily followed.

A similar type of fuselage to that just described was constructed by the Dodge Manufacturing Co.* early in 1917, of about 15 feet length and 40 inches maximum depth, and it weighed only 86 pounds.

Another method of fuselage construction, which might be aptly termed the "box type," consists of four longerons forming the corners of a rectangular section, and which progressively taper towards the tail. The flat sheets of plywood are then screwed on to these longerons, forming a sort of pyramid with curved sides. This method does not give the best aerodynamic results, but is very cheap to employ; moreover, experience has conclusively shown that the flat plywood panels, of from $\frac{1}{8}$ to $\frac{3}{16}$ inch in thickness, cockle and warp, or corrugate, after a little use on machines. Flat sheets used for curved faces give still worse results.

The usual thickness of veneer in either three or five-ply is from $\frac{3}{32}$ to $\frac{5}{32}$ in., and in general the core is about one-half of the thickness of the two face plies or total thickness.

In order to decrease the wrinkling tendency in plywoods, it is usual to make the core relatively thick and of a low density softwood, such as poplar or whitewood, whilst the face plies are of mahogany or birch.

It has been found that spruce plywood gives excellent results for moderately curved fuselage coverings, as it is both light and strong.

In the case of the record breaking Curtiss triplane† of 1919, illustrated in Fig. 147, the body was made of moulded Haskelite plywood.‡ The shell of this fuselage consisted of four long moulded pieces of plywood; namely, the top,

* Of Mishawaka, Indiana, U.S.A. † Known as the "Wasp."
‡ See also "The Design of Monocoque Fuselage," E. Elmendorf. "*Aviation*," 15th September, 1920.

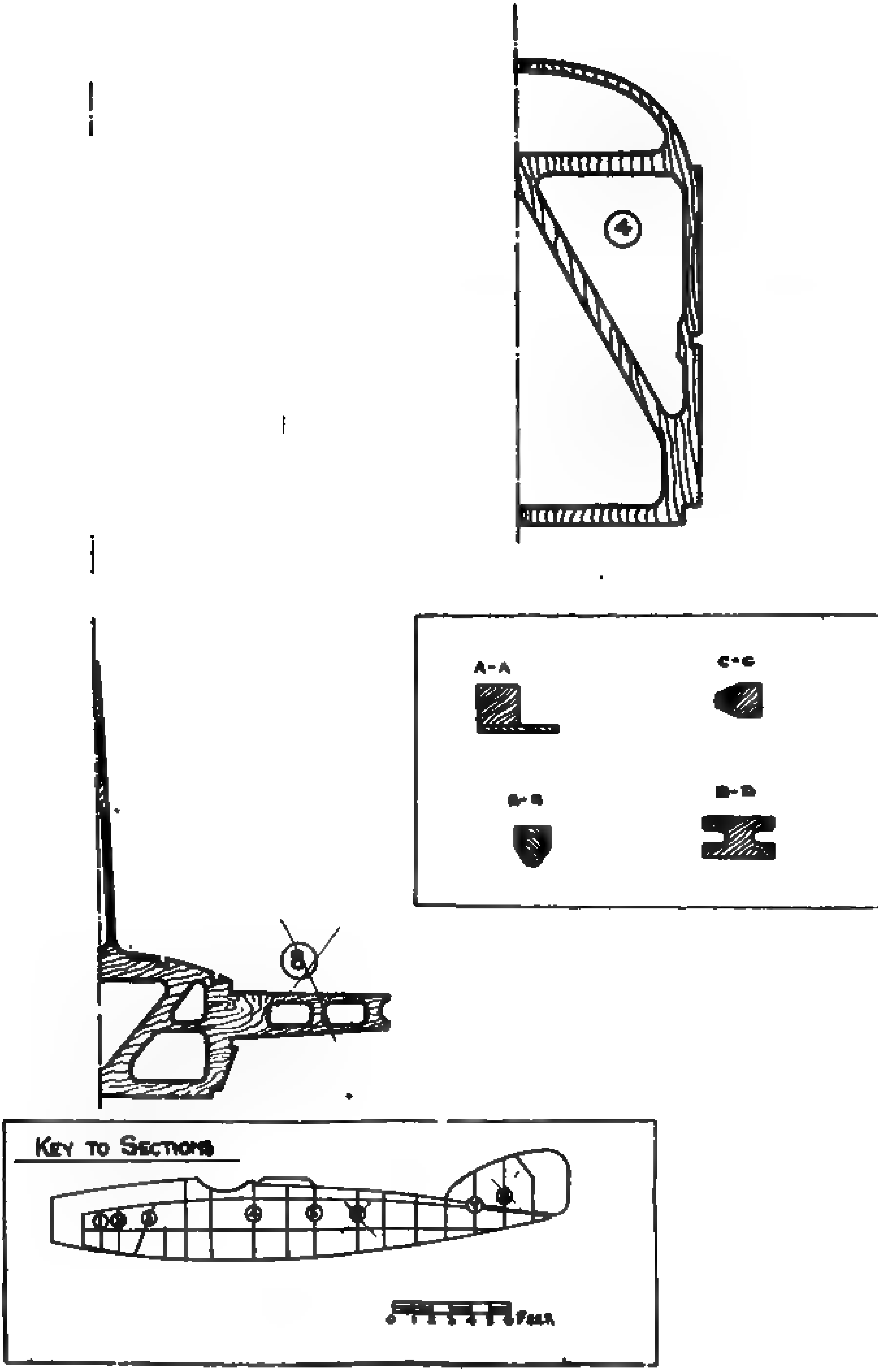



Fig. 146 (A).—Plywood Fuselage Sections.

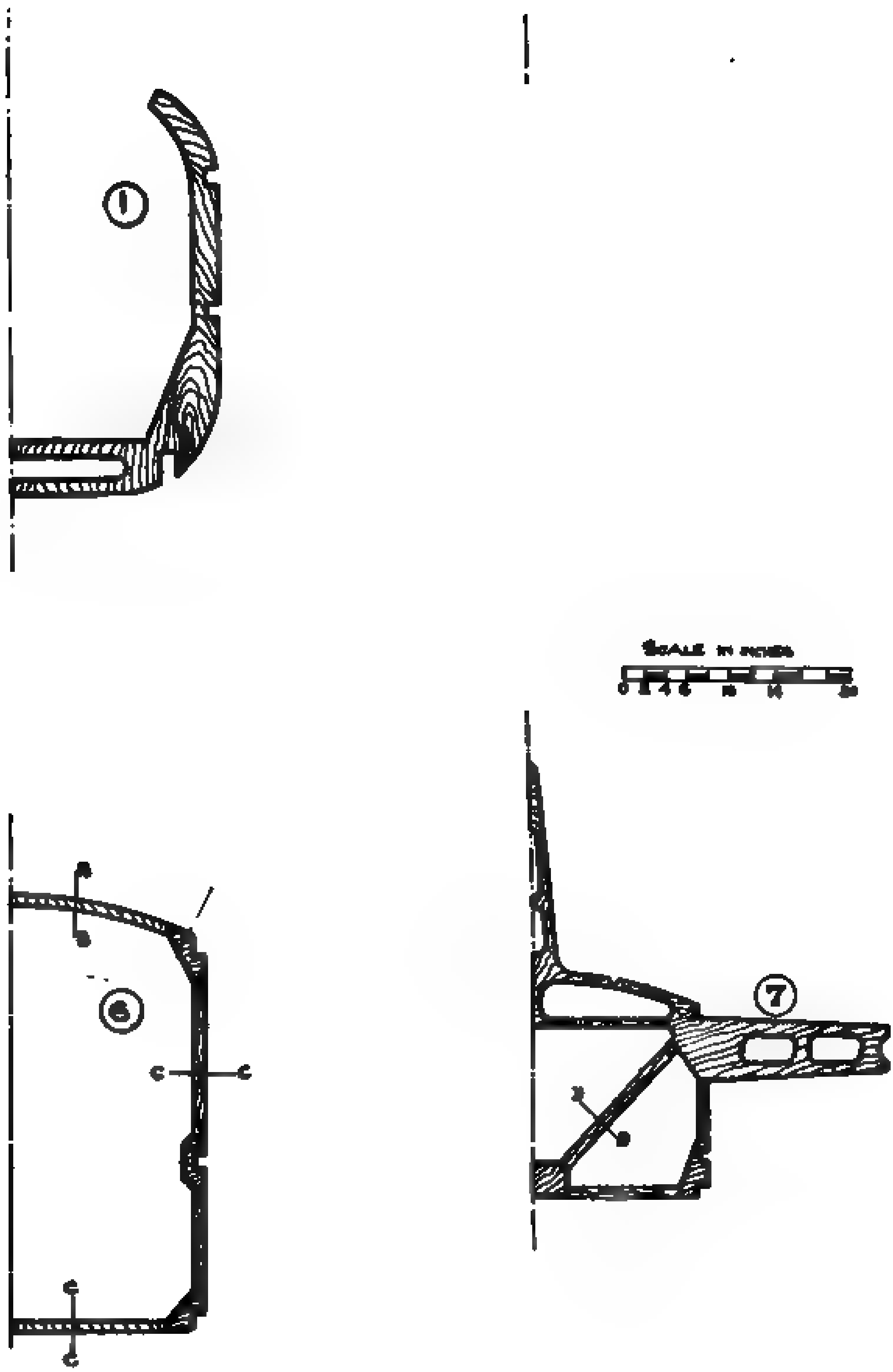



Fig. 146 (*B*).—Plywood Fuselage Sections.

bottom, and the two sides. These were joined together by butt-joint splices on very light longerons.

The plywood panels were first cut to shape and were then boiled and moulded to the proper shapes. In the case of small fuselages, these can be made in two parts only, joined by two longitudinal seams at the top and bottom.

This method of moulding fuselages in plywood is an excellent one for the quantity production of standardized designs, as it eliminates a great deal of handwork and machining.

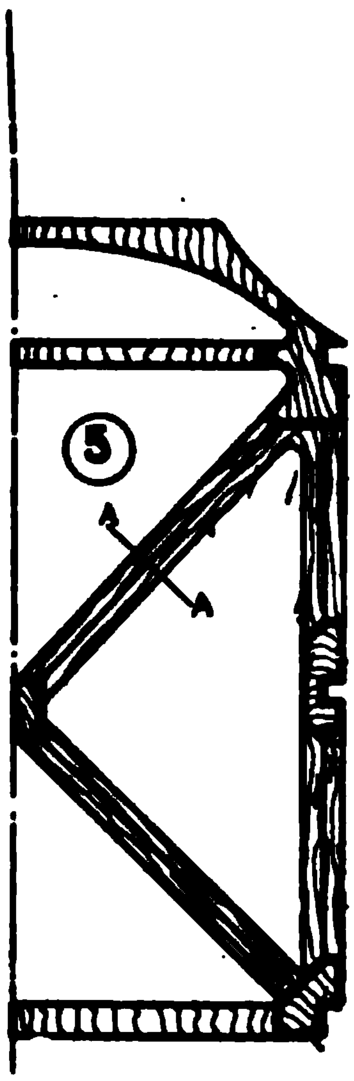




FIG. 146 (C).–PLYWOOD FUSELAGE SECTIONS.

Once the necessary moulds are made, and the cost covered by making a minimum number of fuselages, subsequent ones can be rapidly produced at an exceedingly low cost.

The same remarks apply to the design and construction of standard struts, wing spars, wing covers, floats, etc.

An alternative and more expensive method of making fuselages which is sometimes used, and which resembles that previously described in the case of the Deperdussin monocoque fuselage, consists in making up, first, a solid or heavy wood body to the correct shape of the inside of the required body. This wooden former is so built up that it can be made to collapse by withdrawing a centre wedge-shaped piece or pieces, so as to facilitate the removal of this former when the body is finished.

The veneer employed consists of thin strips of from 4 to 6 inches width ; these are wound spirally about the body former so as to make about one complete turn in the length of the body. After this first layer of veneer is complete, tape of about 2 inches width is wound over the veneer in a continuous strip, lapped about ¼ inch, and glued. Another

Fig. 147.– Example of Plywood Fuselage.

ayer of veneer is then laid, wrapped around the body in a spiral of the same type as in the case of the first, but opposite in direction to it. Next a second layer of tape is wound on top of this. The third layer of veneer is now applied with the grain running in a longitudinal direction. The structure is allowed to dry for about 3 or 4 days, and the collapsible mould is then removed.

FIG. 148.—ILLUSTRATING THE CONSTRUCTION OF THE VICKERS' FUSELAGE.

It is usual to finish the outside of the body with a layer of Utica sheeting, well doped and varnished. The veneer used in the above method is usually one of spruce of from $\frac{1}{32}$ to $\frac{1}{16}$ inch in thickness.

**The Vickers' Construction.**

In the case of the Vickers' Commercial " Vimy " machine, the fuselage of which is of oval section, measuring at its

maximum dimensions about 7 feet high by 4 feet 9 inches wide, the body is built up in two sections, the front half part being in monocoque construction, whilst the rear part is of the usual braced girder construction, employing Ryan struts* as longerons, and swaged tie-rods.

The front half of the fuselage, which is shown illustrated in Figs. 148 and 149, is of elliptical cross-section with a rounded nose ; the shell, or outer covering, is made of Consuta plywood,† consisting of layers of selected spruce, placed with the grain located diagonally, glued, and sewn together.

The shell is attached to box-formers built up of three-ply, one of which is illustrated in Fig. 150.

On each side of the cabin are circular port-holes, glazed with Triplex, and on the port side at the forward end is a door of the roller-shutter type.

The whole of the fore-part of the fuselage, including the doors and window, is water-tight, so that the machine can float in a normal position on the water in emergencies. The monocoque portion above referred to contains the pilot's cockpit, passengers' and luggage cabin, tanks, etc., or, in the event of the machine carrying merchandise only, about 300 cubic feet of space is available, with a floor area of 53 square feet ; the maximum weight allowable for this freight is just over 1 ton.

## COMPOSITE WOOD CONSTRUCTIONS

During recent years, the principles of plywood construction, whereby uniform strength in all directions, combined with freedom from warping, is obtained, have been applied to many other wooden components, such as aeroplane wing spars, hollow struts and tubes, laminated beams, etc.

Although it will not be possible to deal with the subject at length, a few typical examples will be here considered.

* *Vide* p. 543.
† *Vide* p. 523.

Fig. 149.—Interior Construction of Vickers' Fuselage.

**Bentwood Spars.**

A method which has met with much success in practice for making hollow spars of uniform strength is that developed by the McGruer Bentwood Co. It consists primarily of a method of bending flat sheets of silver spruce, previously heated, around suitably shaped formers, and joining the edges by means of a glued scarfed joint. Over the first sheet thus bent is wrapped a second ply which is glued to the first sheet with a strong waterproof glue of the casein type.

The grain or wood fibre of each layer is arranged to lie parallel with the axis of the spar, so that in cross-section the appearance of the bentwood is similar to that illustrated in Fig. 151.

It will at once be evident that this arrangement of the grain of the wood is eminently suitable for hollow struts or beams which are designed to take end-loads, for it gives the maximum resistance to buckling or flexure.

This method of making spars is not only a stronger one than the old laborious spindled-out, tongued and grooved spar method, but is considerably more economical both in time and material.

By suitably selecting the veneers or wood sheets, all defects such as short grain, torse-fibre, knots, and shakes can be eliminated.

Parallel, tapered, or curved spars of almost any length can be built up in this manner, and any curved section, or section consisting of straight lines joined by curves, can be constructed.

Fig. 153 shows one or two typical sections of struts and beams which have been constructed and successfully employed in aircraft and marine work.

It is interesting to note that hollow spars, or booms tapering from a maximum cross-section in the centre to minimum sections at the ends, with either straight or curved sides can be constructed ; in this case, collapsible formers or moulds are employed.

In many hollow strut designs it is necessary to leave solid

Fig. 150.—Box Former for Vickers' Fuselage.

Fig. 151.—Showing Bentwood Spar Construction.

blocks inside, where clips or bolt-holes occur, and in the above method of construction, this can be readily arranged.

On account of their uniform construction, spars made by this method do not warp or bend.

Amongst the applications of this process may be mentioned its use in the construction of hollow circular fuselage struts and longerons for aeroplane fuselages,* hollow tapered streamline struts for inter-plane struts, portable telescopic masts for

FIG. 152.—ILLUSTRATION OF BENTWOOD STRUT SECTION.

telephony or wireless work, cantilever spars for aircraft and other work, ships' masts (lengths up to 60 feet and diameters of 1 foot and above can be made), boat oars, boat-hook poles, punt poles, boat sides or skins, boxes, etc.

It is, of course, necessary to employ more than two skins for the larger diameters, and also thicker veneers, and any thickness of wall can be obtained with this method. For

* The longerons and struts of the cross-Atlantic Vickers' Vimy machine, and also the large 4-engined Handley Page machine, were made of McGruer bentwood struts.

example, a cross-section of 5 inches diameter by 0·2 inch wall in one layer was made in one case, and in another a cross-section of 5 inches diameter by 1·0 inch wall, in four layers.

*A* *B*

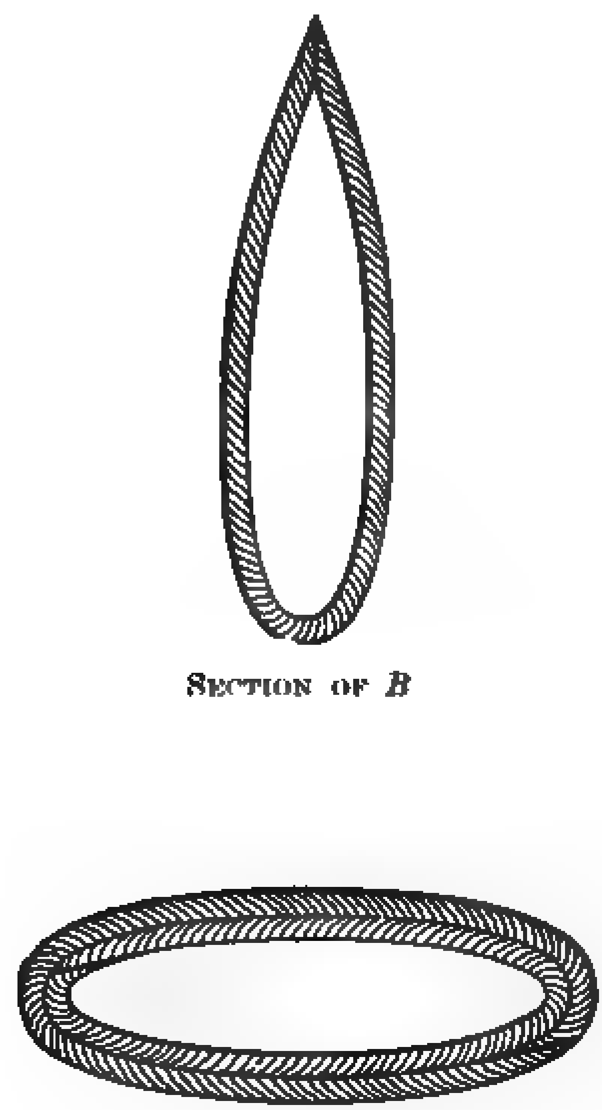



FIG. 153.—EXAMPLES OF BENTWOOD APPLICATION.

**Results of Tests on Bentwood Spars.**

Weathering tests have been made upon bentwood spars by the Royal Aircraft Establishment, in which several specimens were submerged in water at 112° F. for periods of 12 hours without any ill-effect.

Samples have been placed in cold water for periods of 30 days without having their shape detrimentally affected, or without the glued joints opening; these specimens were not varnished or protected in any manner.

The effect of temperature variations upon a hollow spar tends to cause a lengthening or shortening of the circumference and an expansion or contraction in length; the former effect is not serious in the case of a thin-walled spar, but in the case of thick walls, the outermost layer tends to contract more than the innermost layer when the temperature rises, and there is, therefore, a tendency to crack peripherally, that is, along a radial line.

It is well known that edge-grain does not readily break in this manner, as there is a certain elasticity in the spring-wood fibres which allows a definite amount of yielding to occur without fracture; in flat-grained timber the layers of relatively brittle autumn wood fibres very readily become shaky in this respect.

Fig. 154 shows the Euler* curve for silver spruce struts with rounded ends, and it expresses the relation between the crippling load and the "slenderness ratio," that is to say, the ratio of the length to the radius of gyration of the strut.

The corresponding formula for the curve is given by

$$p = \frac{\pi^2 E}{a \cdot \left(\frac{L}{K}\right)^2}$$

where E = modulus of elasticity in pounds per square inch (= 1,600,000 pounds per square inch for good silver spruce)

$a$ = a constant (the value of which is 1·00 for rounded or hingeds truts, and 0·25 for fixed ended struts)

L = length of strut in inches

K = least radius of gyration in inches

$p$ = crippling load in pounds per square inch.

* See Ch. 1, Vol. I of this work.

The three points $A$, $B$, and $C$ marked on the curve shown in Fig. 154 correspond to destruction test results upon bentwood spars ; the point $A$ is for a fixed ended strut, $B$ is for a similar strut with small balls in small sockets at the two ends, and $C$ is for ball ends on hard plates.

In all cases the above formula does not apply for $\frac{l}{K}$ values of less than about 80.

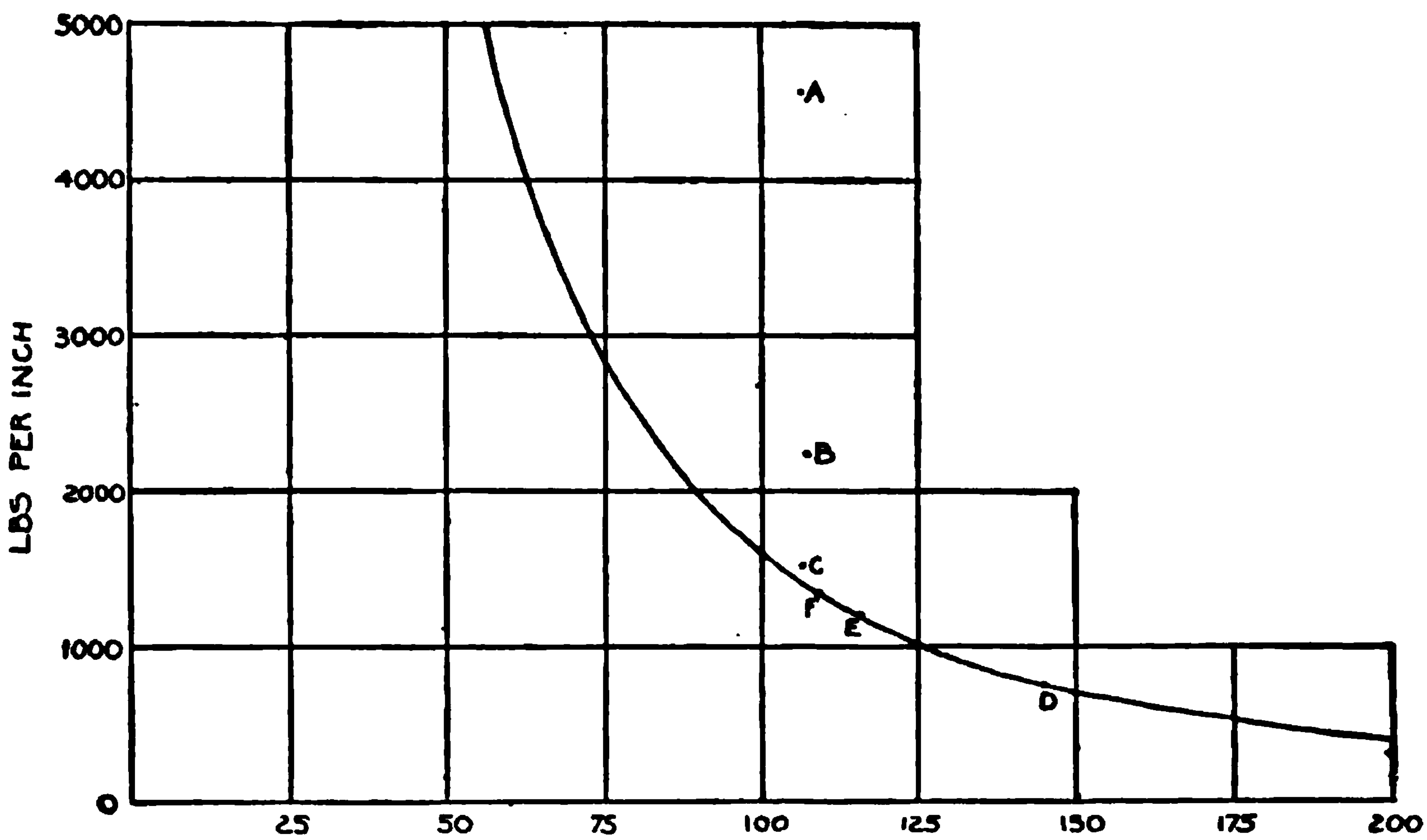



FIG. 154.—EULER'S CURVE FOR HOLLOW STRUTS.

The results shown in Table CL were obtained in various official tests of bentwood hollow circular spars or struts.

In the case of one or two cantilever aeroplane wing spars built to the author's designs, and tested to destruction, the moduli of rupture calculated from the breaking load results came up well to the appropriate values for the sections chosen, and for the material (silver spruce) employed. In designing hollow spars for struts or beams to be made by this process, the thickness of the walls must be so chosen that the strut or beam does not fail by secondary flexure or local buckling.

For example, in the case of a circular strut or beam the minimum thickness should not be less than one-fifth to one-sixth of the diameter, otherwise the full strength is not developed in short struts or in beams.

TABLE CL.

STRENGTH OF BENTWOOD HOLLOW STRUTS.

| *Length in inches.* | *External Diameter (inches).* | *Thickness (inches).* | *Load in pounds.* | *Weight of spar in ounces.* | *Crippling load in pounds per square inch.* |
|---|---|---|---|---|---|
| 19·625 | 1·08 | 0·22 | 2600 | 2·75 | 4420 |
| 25·25 | 1·27 | 0·26 | 3120 | 5·00 | 3770 |
| 39·0 | 1·58 | 0·26 | 3225 | 10·75 | 3015 |
| 55·625 | 1·82 | 0·32 | 3310 | 22·50 | 2205 |
| 21·0 | 1·52 | 0·27 | 5540 | 5·87 | 5250 |
| 62·0 | 3·49 | 0·299 | 10300 | 52·0 | 3440 |
| 67·12 | 3·45 | 0·301 | 10990 | 56·5 | 3700 |
| 38·0 | 1·57 | 0·220 | 4800 | 152·0 | 4420 |
| 67·75 | 2·40 | 0·284 | 4000 | 33·0 | 2125 |
| 113·37 | 3·51 | 0·310 | 4360 | 95·0 | 1400 |
| 68·0 | 3·43 | 0·370 | 12650 | 53·0 | 3570 |
| 124·0 | 3·25 | 0·375 | 4630 | 99·0 | 1180 |
| 64·0 | 3·20 | 0·350 | 11800 | 45·0 | 3750 |
| 100·0 | 3·20 | 0·350 | 5300 | 72·0 | 1690 |
| 124·0 | 4·48 | 0·260 | 7400 | 118·0 | 2125 |
| 11·0 | 1·06 | 0·20 | 2688 | 1·75 | 4928 |
| 12·9 | 1·13 | 0·22 | 3136 | 2·25 | 4928 |
| 18·0 | 1·06 | 0·20 | 2598 | 2·75 | 4704 |

**The Ryan Strut.**

A method of hollow strut construction which has been successfully used in aircraft work is that illustrated in Fig. 155* (diagrams *A*, *B*, *C*, and *D*).

The method of construction consists in building up the tubes, spars, or struts from longitudinal elements of wood, so arranged that the grain runs parallel to the length, and in gluing or

* Designed by A. Ryan and adopted by Messrs. Vickers, Ltd. Also *vide* Patent Specifications Nos. 16,265 (Nov., 1916) and 7,815 (May, 1917).

otherwise attaching the components together, the whole being covered or bound with a fabric or tape which is treated with a varnish or solution, such as one having a basis of cellulose acetate

In building up long spars, a number of short elements may be employed, the joints being staggered so that there

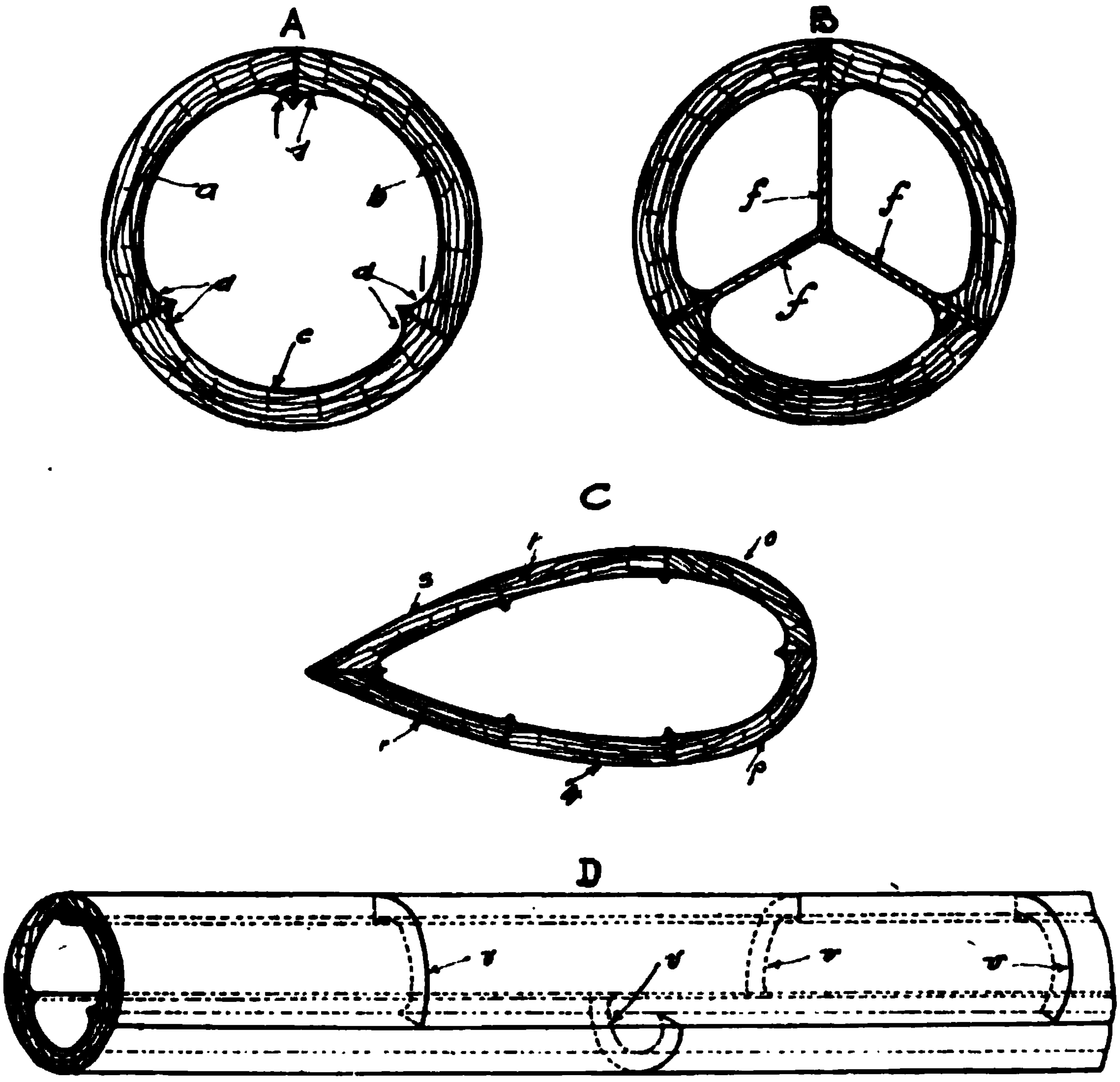



FIG. 155.—THE RYAN STRUT CONSTRUCTION.

is no continuous cross-sectional joint along the length. The method of construction, longitudinally, will be apparent from Fig. 155 (diagram *D*).

If desired, internal metal or plywood stiffeners may be employed in the built-up body, and in the case of hollow struts or spars, such as that illustrated in Fig. 155 (diagrams *A*, *B*, and *C*), it is considered preferable to make the gluing

surfaces of the adjacent sectors rather wider than the general thickness of the joint, in order to obtain a stronger joint.

Any shape of section may be built up in this manner; for example, hollow streamline struts, hexagonal, oval, or square sectioned members, etc. A streamline section is shown in Fig. 155 (diagram *C*).

The results of numerous tests made upon struts of this type show that they give the strength of the solid wood of the same section, and in general fail in the same manner independently of the joints in the strut.

The following formula is employed to give the breaking load, $f$, in pounds per square inch, for struts of different slenderness ratios, that is, $\frac{L}{K}$ values, where $L$ is the length in inches and $K$ the least radius of gyration of the section.

$$f = \frac{f_c + (n+1) f_e}{2} - \frac{[f_c + (n+1) f_e]^2}{2} - f_c \cdot f_e$$

where $f_c$ = compression strength of the timber in pounds per square inch

and $f_e$ = Euler's breaking load in pounds per square inch

$$= \frac{\pi^2 E . A}{\left(\frac{L}{K}\right)^2}$$

where $A$ = area of section:

$E$ = modulus of elasticity in pounds per square inch

= $1{\cdot}2$ to $1{\cdot}5 \times 10^6$ pounds per square inch for pine and spruce

and $n = {\cdot}003 \frac{L}{K}$

The above formula applies to pivoted struts; for fixed ends the above value for $f_e$ would be multiplied by 4.

Table CLI shows some actual early test results for hollow circular Ryan struts, and gives particulars of the moisture content, grain, and elastic moduli.

The struts were made of spruce or pine, and were tested

with free ends ; the elastic moduli were in each case determined from short pieces of the same material.

The results of these tests were considered to be very favourable, as several of the specimens were not made properly and the best quality of timber was not used ; the joints were not always secure, and the grain was inclined, so that there is little doubt that with due precautions appreciably better

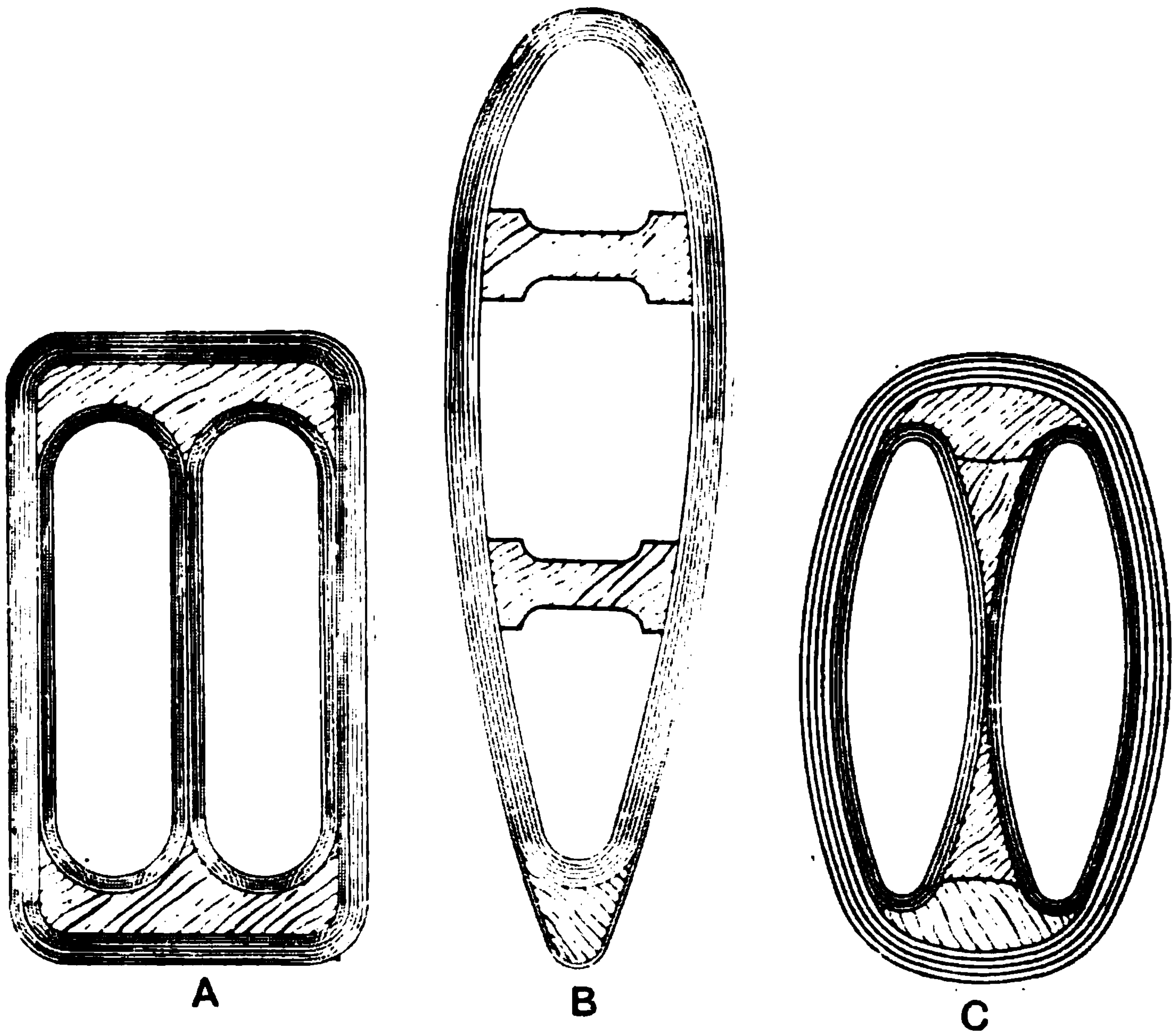



FIG. 156.—BUILT-UP HOLLOW SPARS.

results would have been obtained. Subsequent tests made later confirm this point, and, as previously stated, gave at least the solid section strength for the best grade material.

This method of construction has been employed for the longerons and compression struts of large machines, such as the Vickers' commercial and bombing ones.

**Other Composite Constructions.**

Fig. 156 illustrates another method* of building up hollow

* The Hollow Structure and Aircraft Co., Ltd., London.

# TABLE CLI.

## TEST RESULTS FOR RYAN STRUTS.

| $\frac{L}{K}$ | Equivalent. Diameter. | | Per cent. Moisture (approx.) | Compression. | | Strut Test. Pounds per square inch. | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | *o.d.* inches. | *i.d.* inches. | | *E.* $\times 10^6$ | *fc.* Pounds per square inch | *n* Actual. | *f* Calculate | *fe* Euler. | Grain. |
| 105 | 2·16 | 1·67 | 10 | 1·63 | 7220 | 1055 | 1340 | 1460 | 1 in 10 |
| 107 | 2·16 | 1·64 | 10 | 1·78 | 7700 | 1225 | 1430 | 1550 | 1 in 4 |
| | | | | | | | | | undulating in places |
| 103 | 2·22 | 1·70 | 10 | 1·59 | 6580 | 1180 | 1348 | 1480 | 1 in 5 |
| | | | | | | | | | undulating |
| 67 | 3·32 | 2·70 | 10 | 1·54 | 5200 | 3060 | 2655 | 3360 | O.K. |
| 66 | 3·41 | 2·72 | 10 | 1·50 | 5100 | 1980 | 2690 | 3400 | 1 in 6 |
| 66 | 3·41 | 2·74 | 10 | 1·24 | 5100 | 2090 | 2330 | 2820 | 1 in 6 |
| | | | | | | | | | Gum pocket 4 inches long |
| 58 | 3·92 | 3·03 | 10 | 1·70 | 4330 | 3400 | 3000 | 4960 | O.K. |
| 58 | 3·89 | 3·06 | 10 | 1·76 | 4900 | 3330 | 3290 | 5120 | |
| 59 | 3·84 | 3·03 | 10 | 1·56 | 4850 | 3740 | 3103 | 4480 | Bad in places |
| | | | | | | | | | 1 in 6 |
| 106 | 1·46 | 1·08 | 10 | 1·77 | 5010 | 1540 | 1373 | 1552 | O.K. |
| 106 | 1·46 | 1·09 | 10 | 1·53 | 5450 | 1080 | 1230 | 1360 | 1 in 8 |
| 106 | 1·46 | 1·07 | 10 | 1·67 | 6030 | 1410 | 1325 | 1460 | Slightly undulating |
| 124 | 1·26 | 0·903 | 10 | 1·69 | 4850 | 933 | 950 | 1085 | 1 in 8 |
| 120 | 1·25 | 0·924 | 10 | 1·79 | 5200 | 940 | 1106 | 1230 | O.K. |
| 118 | 1·34 | 0·903 | 10 | 1·68 | 4650 | 1170 | 1075 | 1198 | 1 in 11 |

spars with internal stiffeners, in which a number of veneers are bent to the required shape and are glued together ; solid section pieces glued to the ply, suitably arranged, complete the section required. In this method, dissimilar woods can be employed, and a very wide variety of shapes can be built up.

The examples shown in Fig. 156 are : (*A*) An aeroplane wing spar, designed to take vertical loads with sufficient side rigidity ; (*B*) a streamline strut with stiffening pieces and tail fairing piece ; and (*C*) an elliptical section reinforced so as to take vertical loads.

FIG. 157.—DURALUMIN AND WOOD STRUT SECTION.

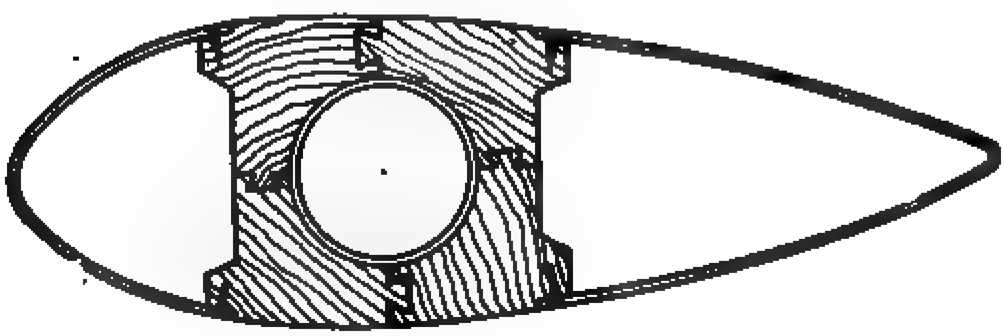


FIG. 158.

Another method somewhat similar to the above, and which was employed some years ago in Germany, consisted in building up hollow spars of all sections by winding strips of thin veneer, spirally, over formers or moulds of the proper shape, and then winding a second layer of veneer strip in a diagonally opposite direction to the first, and gluing in place. Other layers were wound on, in special cases

Fig. 157 illustrates the Sopwith streamline strut construction, in which a duralumin H-sectioned strut is faired, and strengthened by silver spruce or ash pieces.

Fig. 158 shows a patented method* of making streamline

* Messrs. Aylings, of Putney, London.

struts, in which a circular steel strut forming the inner strength member is surrounded by a composite silver spruce block with locked joints, and thin aluminium sheets bent to appropriate shapes form the streamline nose and tail pieces. In this manner the steel and wooden members are designed to

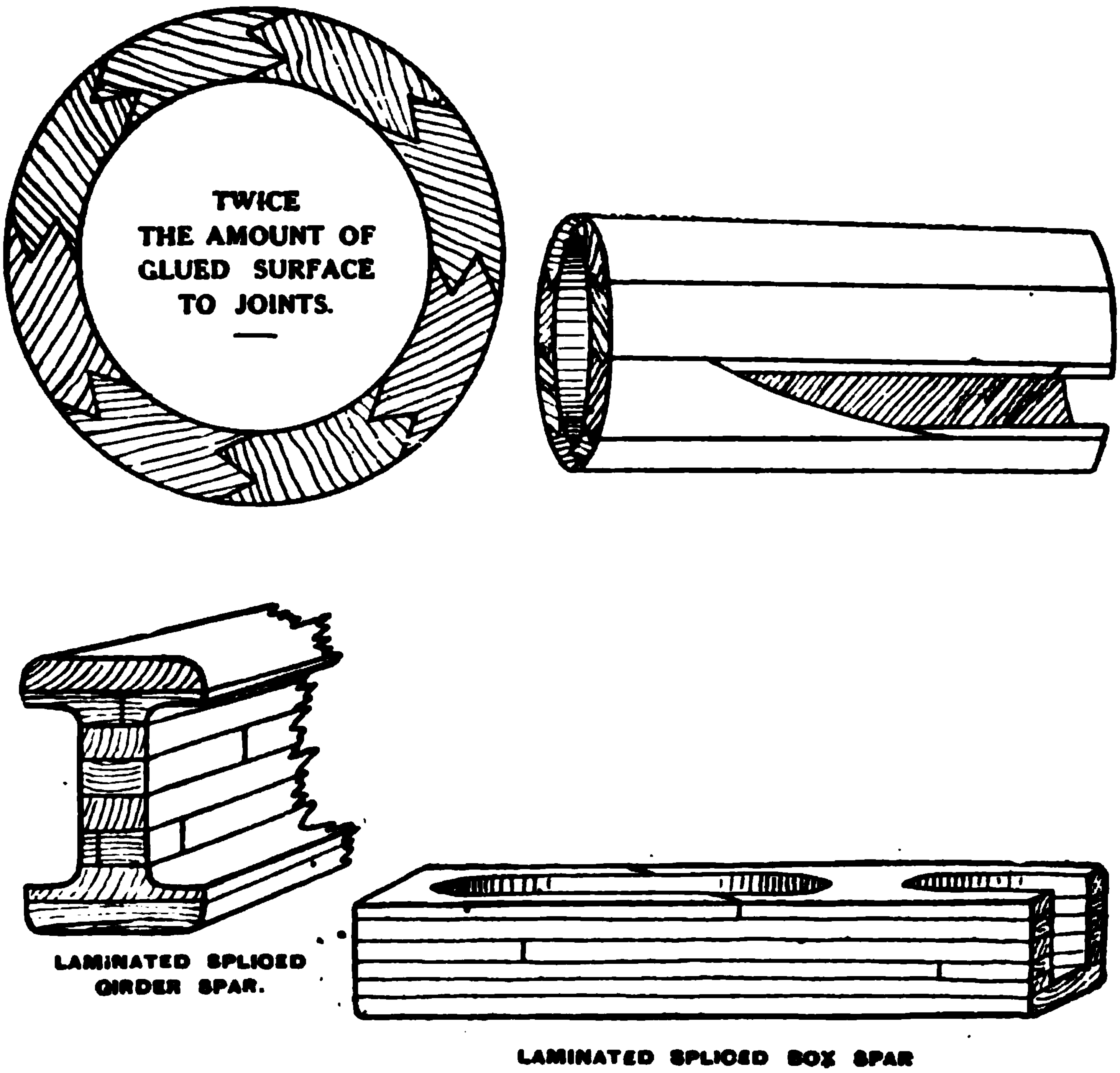



FIG. 159.

take the compression stresses, whilst the aluminium fairing merely streamlines them.

Other examples of spliced spars and struts are shown in Fig. 159. In the lower diagram it will be seen that short lengths of timber can be employed, and much waste thus avoided.

Fig. 160 illustrates a method of building up triangular sectioned, hollow booms for rigid airship girders, in which

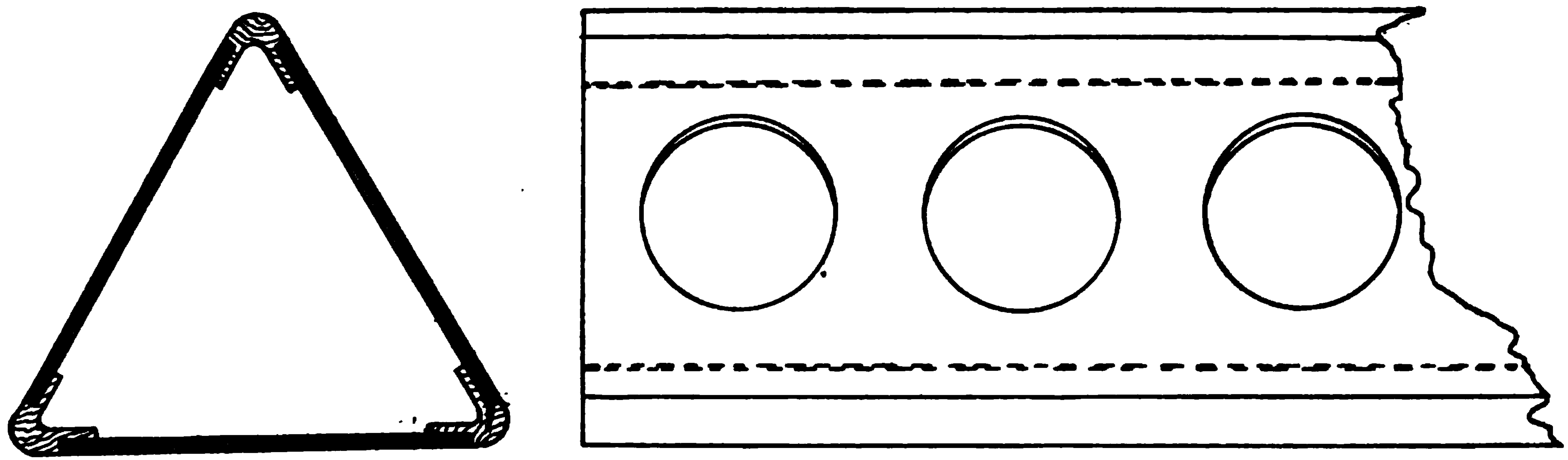


FIG. 160.—AIRSHIP WOODEN GIRDER.

the three apical blocks are connected by plywood sides, suitably lightened. A girder of this type, 36 inches long, weighing only 12 ounces, when tested as a fixed-ended strut gave a breaking load of over 10 tons.

Fig. 161 depicts a built-up aeroplane spar* employing the Warren girder principle. In the case of wing-spars for very large machines, the ordinary box-girder method gives very thin sides for the required strength, and local buckling is liable to result; if the sides are made thicker, then the weight of the spars increases unduly. In the method illustrated, the spar will be seen to consist of two Warren girders displaced

FIG. 161.—DIAGRAM OF THE TARRANT SPAR CONSTRUCTION.

relatively to each other, and it will be observed that short lengths of timber can be employed economically. It was estimated that this method of construction gave a wing-spar at least 10 per cent. lighter than that of a box-spar, with the thinnest possible sides.

**Built-up Wing Spars.**

In the case of aircraft spars used as beams or struts, or as both, it is very essential that the maximum strength for weight is obtained, and that the material is of uniform strength throughout.

Silver spruce has been largely employed for smaller spars,

* The Tarrant Spar.

which are spindled out to an I-section, except where the struts or clips come, when a solid rectangular section is left.

In the case of larger wing-spars, and where spruce is not available, the component or built-up wooden construction is favoured.

Fig. 162 illustrates some typical wing-spar sections which have been actually employed. In deciding the merits of same, due attention should be given to the resulting strength

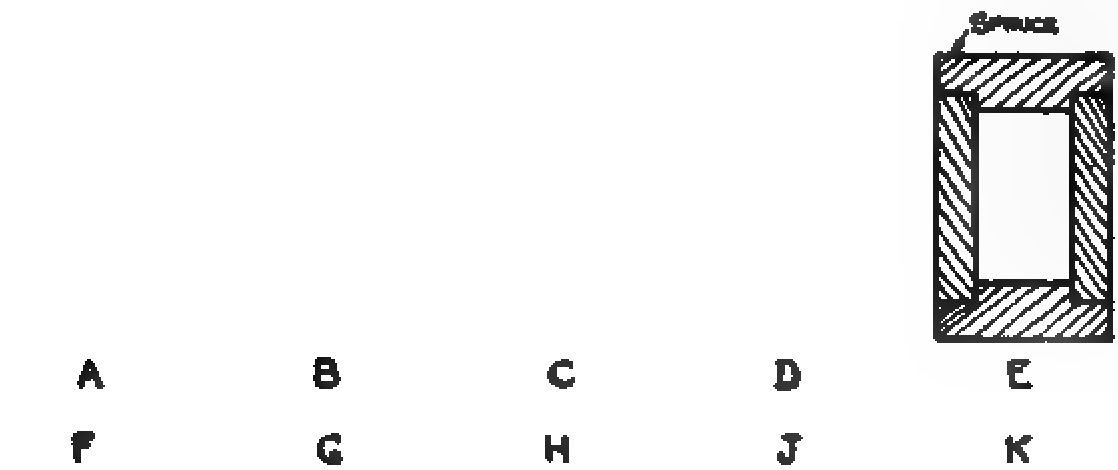



FIG. 162.—EXAMPLES OF BUILT-UP SPARS.

modulus of the section ; that is to say, in the case of spars of the same depth, to the relative moments of inertia of the sections, to the disposition of the grains of the components and to the number and dispositions of the glued joints.

The construction shown in *A* (Fig. 162) is not very economical, whilst in *B* the useless portion has been eliminated with the result that a better section has been obtained. Sections *C* and *D* are both good constructions, using only

small thicknesses for the individual members, and a minimum of glued joints.

The box-sections shown in diagrams *E*, *F*, *G*, and *K* all possess greater lateral rigidity than in the case of the I-beam sections, and are less likely to twist; *F* and *G* are particularly good sections. Section *H* employs only thin wooden strips, and although strong in torsion does not dispose its material in the best manner for vertical bending loads.

Section *K* is very rigid, but is obtained by relatively more expensive and wasteful manufacturing methods.

All of these box-sections are usually bound with a spiral layer of glued tape, for protection purposes; the strength is, however, but little affected.

**Splices in Spars.***

Splices or joints are employed, in the case of wooden members, in order to economize material, and in certain cases in which long lengths have to be built up from shorter straight grained pieces.

A good splice should be as strong as the original timber, in bending, tension or compression, or a combination of both; it is not difficult to obtain equal strength except, perhaps, in the case of compression members. It is further essential that the splice should be fairly simple to make and inexpensive in construction.

It has been shown, as a result of official tests upon various spliced members, that within limits the larger the area of the glued surfaces the stronger the splice is, and also that long splices are stronger than shorter ones; the best form of splice, of the plain scarfed type, Fig. 163 (*B*), has a slope of from 1 in 9 to 1 in 14.

It is advisable to peg or screw the joint at intervals and to

* A comprehensive account of tests upon various splices is given in "An Investigation into Various Types of Timber Splices for Aeroplane Construction," G. W. C. Kaye and J. Hudson Davies. *Aeronautical Journal*, Sept., 1920.

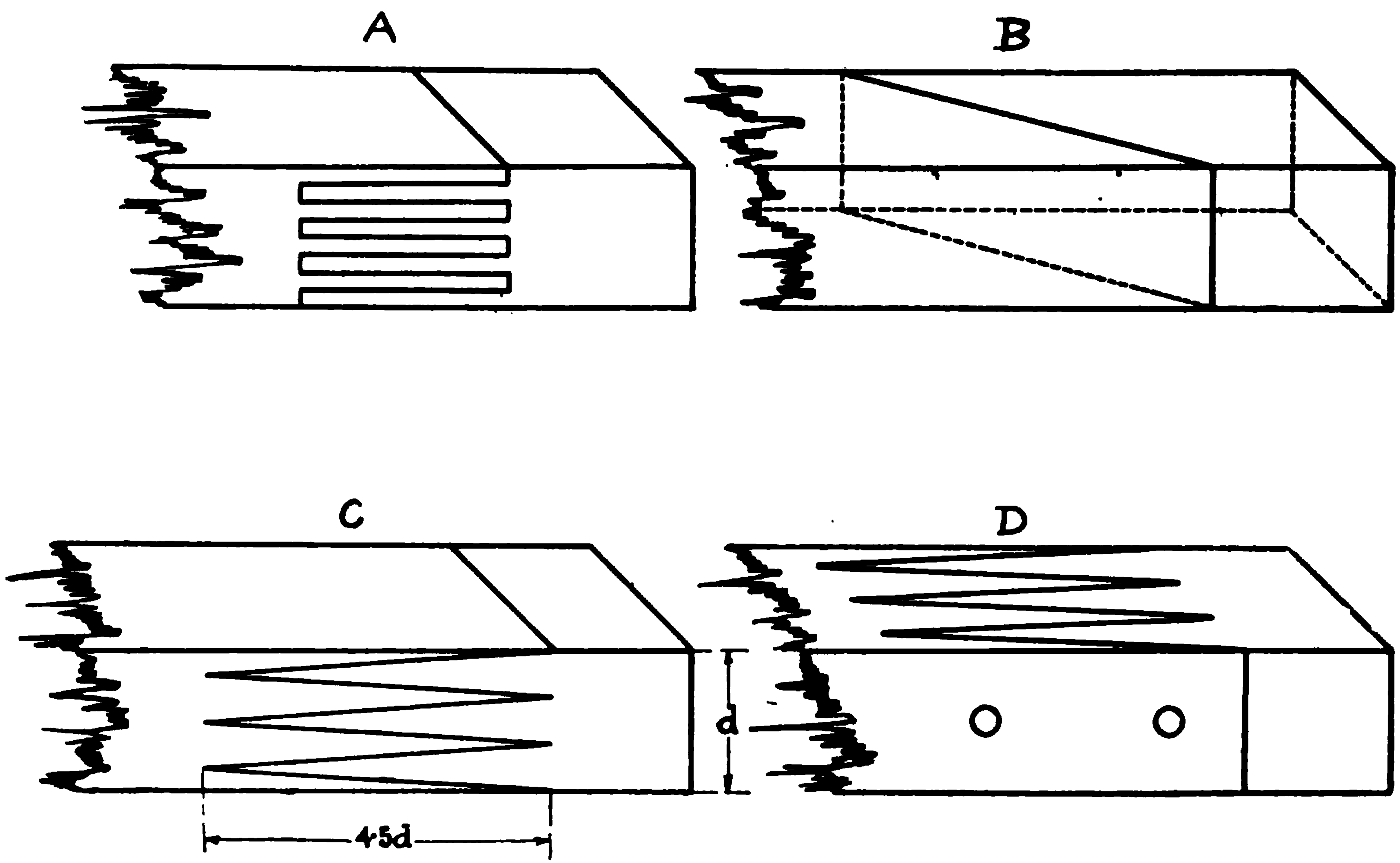



FIG. 163.—TYPES OF SPLICES IN GIRDERS OR BEAMS.

securely bind same with Egyptian tape glued in position; this is a precaution against failure of the glue.

Fig. 163 (*A*) shows a fingered splice, in which the surfaces are horizontal; a large gluing area is obtained in this way, and the efficiency of this type of joint varies from 90 to 100 per cent. under combined bending and direct compression.

Fig. 163 (*B*) shows a plain scarfed splice. When the slope of the splice is 1 in 4, the efficiency for the glued and taped joint is about 50 per cent.

When the slope is 1 in 8, the efficiency for the joint is about 90 per cent.; pegs are inserted in this case along the centre line of the spar. When the face of the scarf is vertical the efficiency is nearly 100 per cent.

An improved form of scarfed joint, which is used in America, provides serrated surfaces for the sloping face, so that a much greater gluing area is obtained.

Fig. 163 (*C*) illustrates a fingered joint, with the sloping surfaces in a horizontal disposition; such a splice has an efficiency of about 95 per cent.

Fig. 163 (*D*) shows a similar splice, but with the glued faces vertically disposed; an efficiency of about 103 per cent. was obtained in tests of this form of splice, using two wooden pegs as shown.

This type of fingered splice, with its variations, is probably one of the most efficient of any, as the gluing areas are very large, and the components are arranged so as to approximate to the fibre disposition of the wood itself.

Fig. 164 shows the standard Air Ministry method of making spliced joints in aircraft members, such as longerons. The splice is of the plain sloping type, with a slope of 1 in 9; it is pegged with ash pegs in seven places, the pegs being staggered in position. The joint is bound at each end for a width of three times the breadth of the spar, with three layers of glued fabric.

Spliced joints are employed in wing-spars, longerons, and similar members; in the case of longerons, the splice should

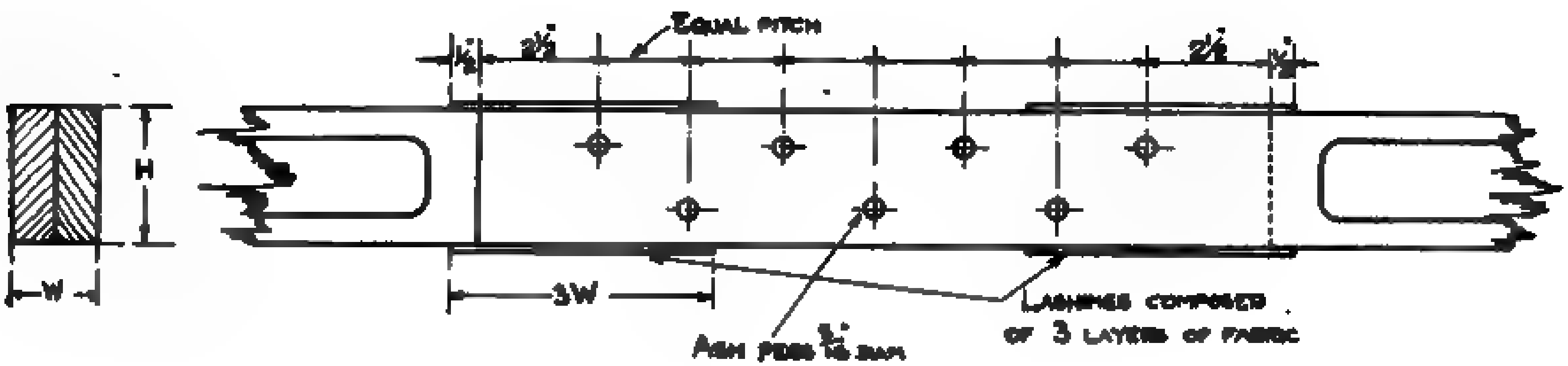



FIG. 164.—AIR MINISTRY SPECIFICATION FOR SPLICED JOINT.

be arranged at a place distant about one-third of the horizontal distance between the vertical struts. As a general rule, spliced joints should be placed at the points of inflexion, or zero bending-moment, of the spar, but they must be kept clear of positions at which concentrated loads occur.

In the case of plywood, laminated or composite wooden members, each lamination or component should be plain scarf-spliced separately.

## R.A.E. Specification for Three-Ply Wood.

1. Plies.—The two outer plies are to be of ash or birch, and the inner ply is to be of either aspen or American whitewood.

2. The three plies are to be of approximately equal thickness.

3. The plies must be firmly glued together.

4. Weight.—The weight of the plywood when varnished must not exceed ·7 pounds per square foot for $\frac{3}{16}$ inch thickness, and proportionally less or greater for other thicknesses.

5. Water Test.—Test pieces taken from any board will be tested by total immersion in water at a temperature varying between 110° and 120° F. for 12 hours, after which it will be dried in the air under normal conditions.

6. The plies must not part from each other in any respect after the completion of this test.

7. Rejection.—Should any test piece fail to comply with any of the above conditions or tests, the board or boards represented by the defective specimen will be rejected.

8. The manufacturer must bear the cost of the depreciation in value of any rejected material due to test pieces being cut therefrom.

9. Samples. — Any samples submitted must have superficial dimensions of not less than 12 inches by 12 inches.

## R.A.E. Specifications for Three-Ply Wood for Wing Ribs.

1. Plies.—The two outer plies are to be of ash or birch and the inner ply is to be of aspen or American whitewood. The wood must be entirely free from knots, shakes, or filling of any kind.

2. Each ply is to be of uniform thickness throughout, and the thickness of the centre ply must be between two-fifths and three-fifths of the full thickness of the board.

3. The plies must be firmly glued together, after which the boards must remain perfectly flat.

4. The grain of the two outer plies must run lengthwise and the grain of the centre ply at right angles to it.

5. Dimensions.—The boards are to be such that strips varying from $4\frac{1}{4}$ inches to $4\frac{1}{2}$ inches, or $5\frac{1}{4}$ inches to $5\frac{1}{2}$ inches wide (according to order), may be cut which will be entirely free from all outer ply joins.

6. Weight.—The weight of the plywood when varnished must not exceed ·58 pound per square foot for $\frac{5}{32}$ inch thickness, and proportionally less or greater for other thicknesses.

7. Water Test.—Test pieces taken from any board will be tested by total immersion in water at a temperature varying between 110° and 120° F. for 12 hours, after which it will be dried in the air under normal conditions.

8. The plies must not part from each other in any respect after the completion of this test.

9. Rejection.—Should any test piece fail to comply with any of the above conditions or tests, the board or boards represented by the defective specimens will be rejected.

10. The manufacturer must bear the cost of the depreciation in value of any rejected material due to test pieces being cut therefrom.

11. Samples.—Any samples submitted must have superficial dimensions of not less than 12 inches by 12 inches.

## CHAPTER XIV

# THE X-RAY METHOD OF EXAMINING MATERIALS

AN extremely useful method of examining the internal structure and disposition of materials has been evolved, thanks to the recent advances in the construction of X-ray apparatus.

The method, briefly, consists in photographing or viewing through a suitable screen the material to be examined, using the high potential X-rays produced by a special type of X-ray tube, the rays passing right through the material to the plate or screen on the other side. If the material is uniform in thickness and homogeneous in structure it will give a uniform photographic " shadow " image, but if homogeneous, and of varying thickness in the direction of the X-rays, it will give a shadow image on the photographic plate, varying in density according to the thickness of the material. Thus, where the material is thickest the X-rays do not pass through to the same extent as through the thinner parts, and a print, or " radiograph," as it is termed, from the X-ray negative will reveal the greater thicknesses as darker portions, whilst the thinner parts which allow a greater proportion of the X-rays to pass, will give a lighter image on the print, due to the more intense photographic action on the plate.

It will now be evident that if a radiograph be taken of a material of uniform thickness having internal blow-holes, air bubbles, or flaws, the result will be a dark patch corresponding to the uniform material, with light spots or streaks corresponding to the bubbles or defects. In this manner it is possible, by taking suitable precautions, to examine the interiors of materials, and, further, by taking photographs in planes at right angles to locate the position of the defects.

An example of the results of an examination of welded

joints in aluminium plates is shown in Figs. 165 and 166. The former photographic reproduction shows a bad welded joint, for the joint of the two plates is clearly seen, and the irregular lighter patches around the line of the joint indicate imperfect junction, thinner metal, and occluded gases. The denser contour around the joint shows a greater total thickness of metal around the joint. Fig. 166 shows a fairly good weld in aluminium, for, although the deposited metal varies in thickness at the joint, no defects or joint line can be detected.

It is apparent that, if properly applied, the X-ray method, which is a non-destructive one, will afford valuable evidence of the internal structures of materials.

**Applications and Limitations.**

The applications of the X-ray method are numerous, and its adoption is extending rapidly.*

Originally applied to physiological purposes, such as the examination of the heart, stomach, and other organs of living subjects, where the resistance to the penetration of the rays was comparatively weak, it has been extended to the examination of timbers and metals, where the greatest resistance to penetration occurs.

It is now possible to detect internal flaws, blow-holes, etc., in steel plates and castings for thicknesses varying up to 4 and 5 inches, and apparatus is now being constructed to deal with thicknesses of steel and iron up to 9 inches.

The thickness of a material which it is possible to examine varies approximately inversely as its density, or atomic weight, so that in the case of aluminium, say, it is possible to examine between two and three times the thicknesses of metal, as compared with steel, under the same conditions.

In the case of timber, in which the density is low compared with steel, thicknesses up to 18 inches to 24 inches can be dealt with for general examination purposes, although for

* An excellent account of the progress in this subject is given in a collection of Papers, entitled "The Examination of Materials by X-Rays," published by the Faraday Society, 10 Essex Street, London.

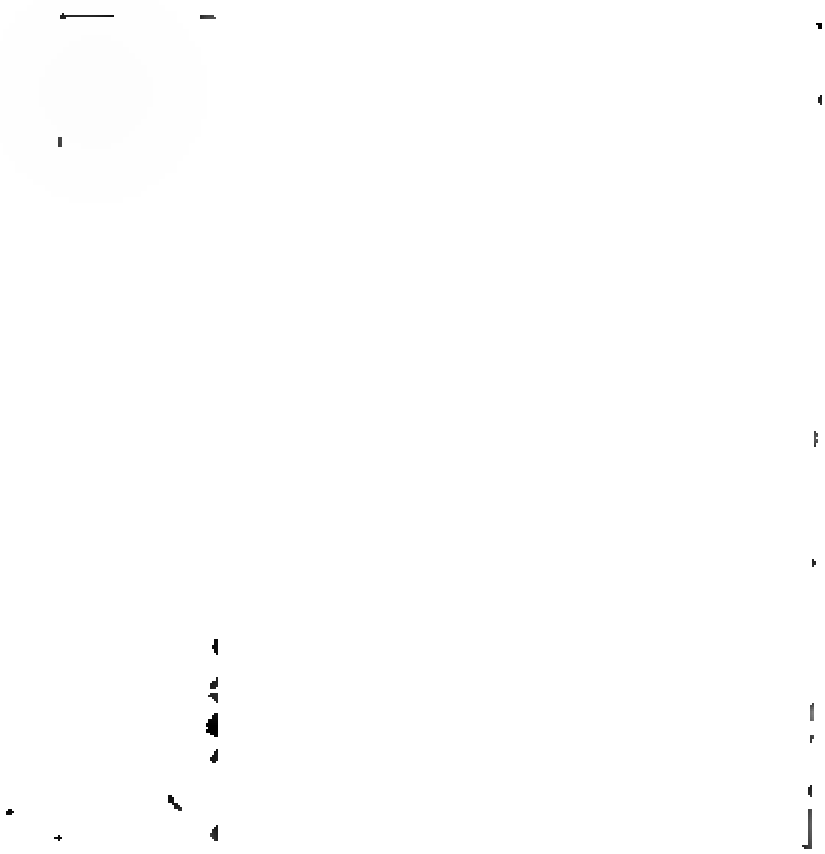


Fig. 165.—Showing Bad Welded Joint in Aluminium Plate.

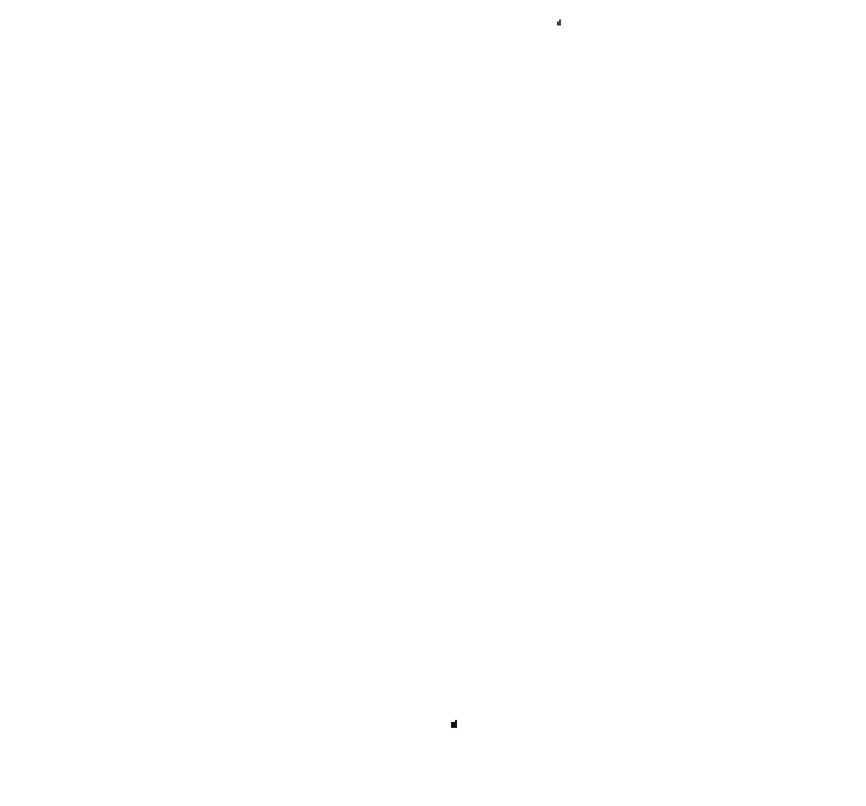


Fig. 166.—Showing Good Welded Joint in Aluminium Plate.

the finer examination of such defects as compression, shakes, incipient rot, etc., smaller thicknesses are advisable.

In the case of steel plate, it is possible to readily detect a flaw of less than 1 millimetre diameter in a 1 inch plate.

**Examination of Castings.**

The X-ray method is a valuable one, and one which is being widely adopted for examining ferrous and non-ferrous castings for internal defects.

If the castings are not too large, each of them may be examined as a routine, and it is possible to locate the faults either by the stereoscopic radiograph method, or by taking two or three radiographs in different directions.

It is possible that such a regular examination of production castings may lead to an association of the location of the defects with the method of casting and the metal employed.

As an instance of this may be mentioned the case of copper castings. Ordinary cast copper, as used for high electrical conductivity fittings, is porous and full of blow-holes, so that the mechanical strength and electrical properties are seriously impaired.

If the cast metal be treated with a deoxidizer to remove the occluded gases, the blow-holes may be eliminated, but usually only at the expense of diminished conductivity owing to the presence of a small amount of the deoxidizer in the cast metal.

The X-ray method* at once enables the copper castings to be examined for porosity and presence of the deoxidizer. When boron-suboxide is used as a deoxidizer, the copper is deoxidized without combining with the deoxidizer, and the resulting castings are homogeneous, sound, and free from blow-holes; this method is now widely used commercially for the production of copper castings.

Fig. 167 shows a radiograph† of a block of ordinary cast

* "Application of the Coolidge Tube to Metallurgical Research," Dr. W. P. Davey. *The General Electrical Review*, Feb., 1915.

† See footnote, page 560.

Fig. 167.—Radiograph of Cast Copper (*Left*) and "Boronized" Copper (*Right*).

pure copper (on the left), and also one of a block of "boronized" copper (on the right); the difference in the structure is so apparent as to obviate further explanation.

Fig. 168 shows a radiograph* of part of a steel casting in which there was an internal flaw, not apparent from an external examination; the radiograph at once reveals the presence of this flaw. The small circle shows the position where a piece of the casting was afterwards punched out; although neither the top nor the bottom surface of the punched out piece showed any defect, the sides of the punching showed the transverse hole previously indicated by the radiograph.

**Welded and Similar Work.**

An example has already been given on p. 561 illustrating the application of the X-rays to testing welded joints for efficiency; the radiograph at once reveals by the lighter spots or patches places where blow-holes or bad contacts occur, and the uniformity of the added metal is revealed by the uniform density of the photographic image of the joint.

In the cases of brazing and soldering, joints may be readily examined by means of radiographs; a good example of the examination of a soldered joint was in the case of the outlet pipe of a cross-Atlantic aeroplane, which failed during the flight attempt. A radiograph of this joint taken afterwards indicated by numerous lighter patches upon a darker background representing the joint, that at the former places the solder had not adhered to the surfaces, and that the joint was therefore a faulty one.

In the case of welded steel tube manufacture, the X-ray apparatus affords a useful method of examination of the results. Fig. 171 is a radiograph of a badly welded steel tube, the thin white line indicating that the two surfaces did not properly adhere. The proper adherence and good quality of the joint would have been shown by a uniform slightly

* Messrs. the British Thomson Houston Co.

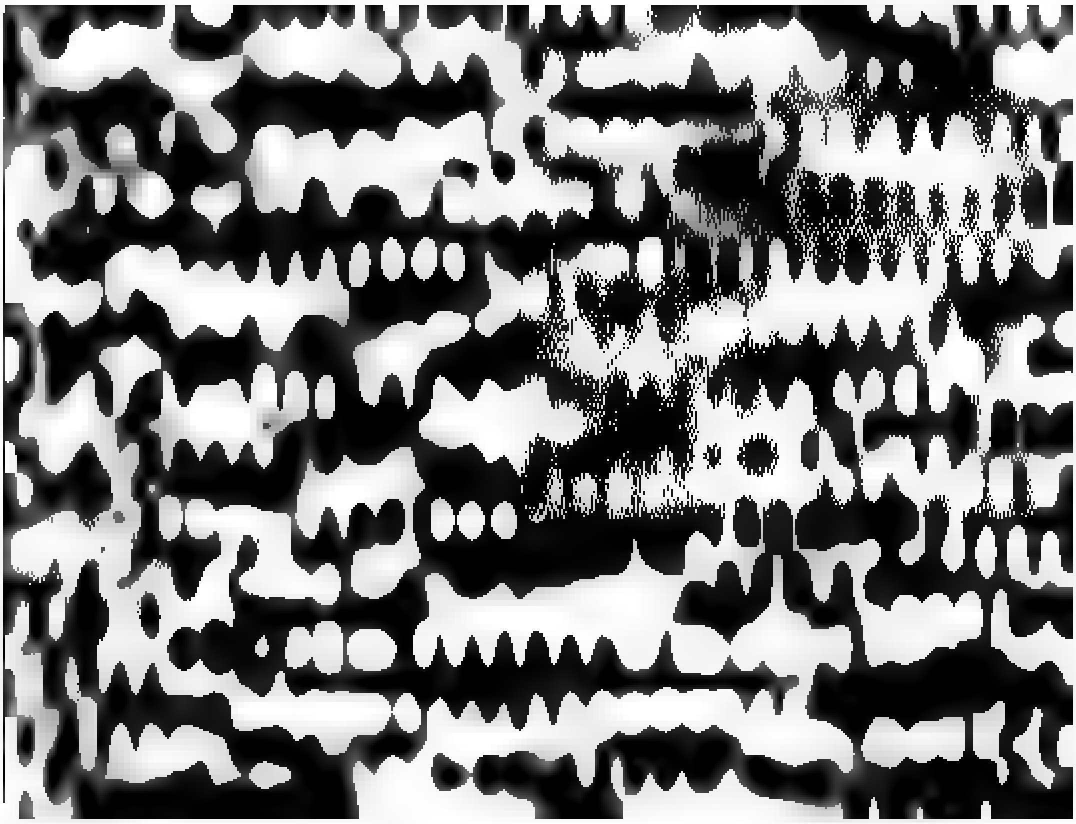


FIG. 168.—RADIOGRAPH OF STEEL CASTING.
*(Circle denotes where metal was punched out afterwards.)*

FIG. 169.—PUNCHING FROM DEFECTIVE CASTING SHOWN IN FIG. 168.

FIG. 170.—UPPER AND LOWER SURFACES OF PUNCHING FROM DEFECTIVE CASTING, SHOWING NO INDICATION OF FLAW.

Fig. 171.—Radiograph

darker band right along the joint, with no white streaks or spots; the slightly darker band is, of course, due to the slightly increased thickness at the weld.

**Examination of Timber.**

As previously mentioned, the X-ray method is a valuable one for examining timber, both in the bulk and when built up into components; particularly is the method of value in connexion with aircraft inspection work.* For most purposes "soft"† X-ray tubes are employed, the alternative spark gap being 1 to 2 inches. The usual equipment for aircraft work consists of a high tension transformer and Coolidge X-ray tube (described on p. 573), giving an abundance of rays of long wave length; the current used is about 15 milliamperes.

In connexion with the examination of original timber, the X-ray method successfully reveals the presence of local differences in density, internal knots and resin pockets, grub holes, etc. The position of the defects can be ascertained without difficulty by taking radiographs in two suitably selected planes at right angles, or by means of stereoscopic radiographs.

If the specimens are not too thick, it is possible to detect compression shakes, incipient rot, and spiral grain. The differences between the light spring and denser summer growths, that is, the annual rings, are readily revealed by the X-rays.

The more important use of X-rays, however, is for the examination of timber components, particularly in the case of hollow timber parts such as box-spars and struts, as used on aircraft, and for plywoods.

Some interesting examples of the application of the X-ray method to the detection of faults of workmanship are given in the Paper referred to below.

* *Vide* "The Examination of Aircraft Timber by X-Rays," by R. Knox and G. W. C. Kaye. *The Rontgen Soc. Proc.*, April, 1919.

† *Vide* p. 575.

In many cases box spars are covered with fabric, veneer, or plywood when finished, making inspection of the interior impossible otherwise than by the X-ray method. The X-ray

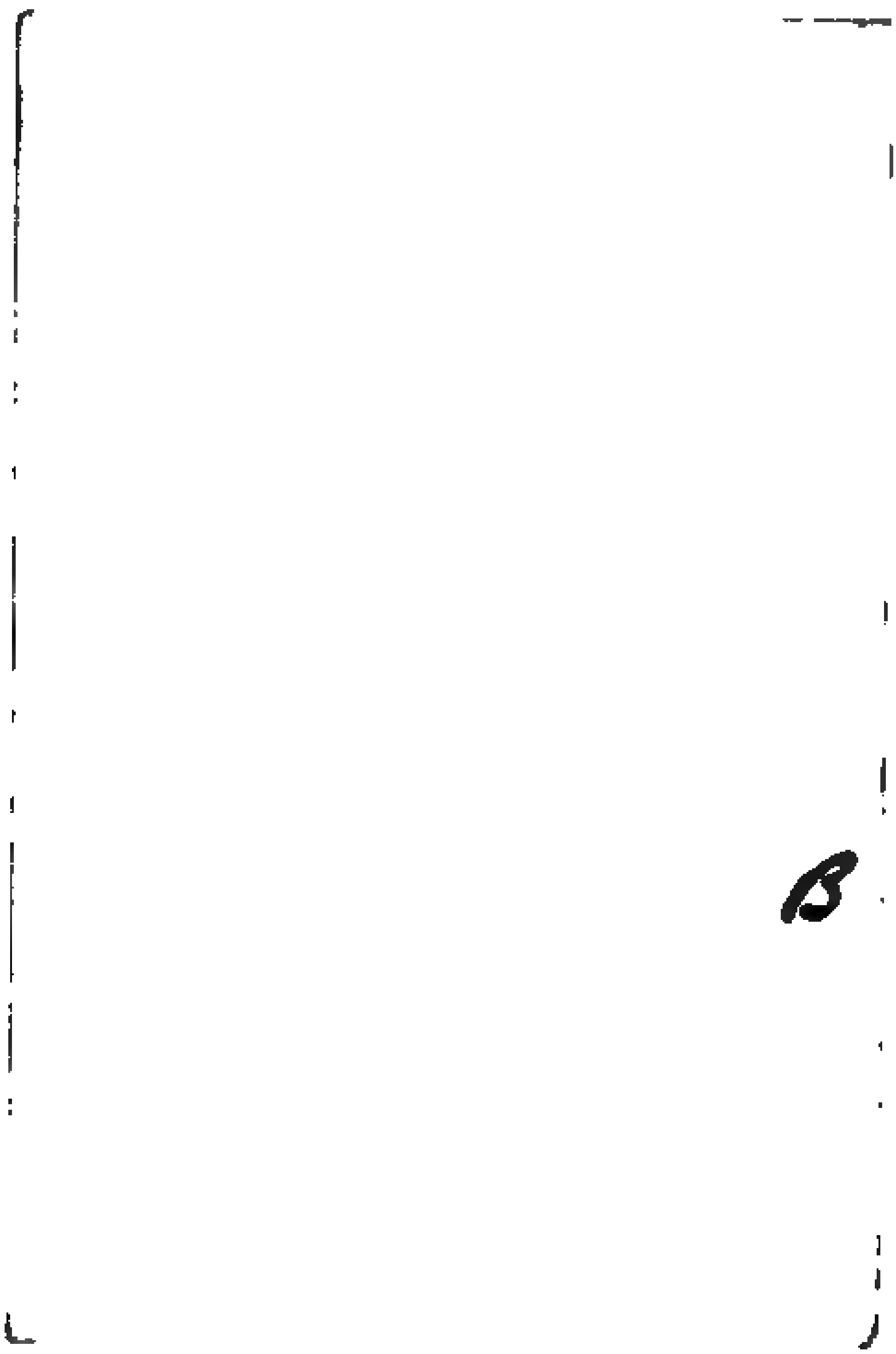


FIG. 172. RADIOGRAPH OF BADLY FITTING STRUT IN SOCKET.

photograph or screen image at once shows whether, for instance, the strengthening blocks inside a hollow spar are properly fitted, or are split by the wood screws holding them

in place, whether the two halves of a hollow spar are of equal wall thickness and are properly glued, or whether the wooden-end blocks properly bed in the case of compression members fitted inside metal sockets (as, for example, in the case of the interplane strut sockets).

Fig. 172 shows a radiograph of such a wooden interplane strut which was supposed to be correctly fitted inside an aluminium socket; it will be seen that the strut did not " bottom " by the amount marked *B* in the radiograph.

Fig. 173 is a reproduction of a radiograph showing the front and side views of a laminated wooden spar. It will be seen that, hidden in the middle layer, are two knots and a grub hole (which were not evident from an outside examination).

A further example of the use of the X-ray method for examining important plywood joints is shown in Fig. 174. Here the plywood forms the outer covering of a built-up spar, and it is evident that there are somewhat serious gluing flaws in the former.

The radiograph can also be employed to show whether wood screws or bolts are properly fitted in timber parts.

The above examples are only typical ones from those covering a wide field.

**Other Miscellaneous Applications.**

Apart from the examples previously given, the X-ray method is valuable, in general, for examining the interiors of finished mechanisms, components, and parts which it is not desirable to disturb during inspection.

For example, it is possible to examine the interior of loaded cartridges, of shells, grenades, bullets, torpedoes, clocks, watches, switches, etc.

In the case of moulded insulations around metal fittings or cores, such as are widely used in electrical work, the junction of the materials may be satisfactorily examined.

Enclosed electrical insulations, such as the circuits in electric kettles, soldering irons, and in airmen's electrically

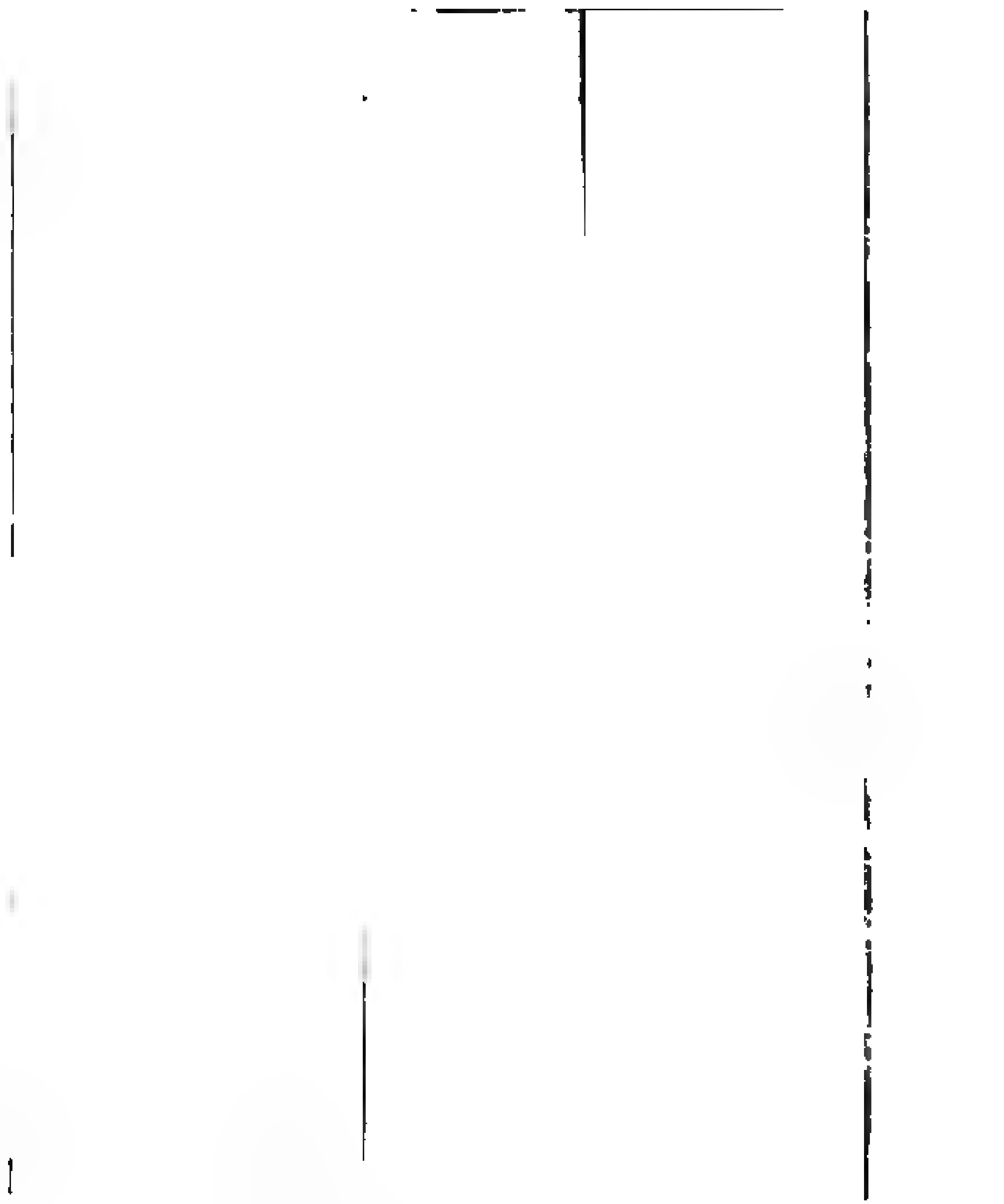


FIG. 173.—RADIOGRAPHS OF LAMINATED SPAR SHOWING GRUB HOLES AND KNOTS.

FIG. 174.—RADIOGRAPH OF PLYWOOD, SHOWING GLUING DEFECTS.

heated clothing can be readily examined, and any breaks in, or fusing of, the wires detected and located at once.

It is possible to radiograph engine parts such as cylinder blocks, pistons, carburettors, etc.; the union of a bearing lining metal and its containing shell can also be examined.

The distributor of a magneto can be internally inspected and faults located by the X-ray method.

Numerous other applications are, of course, possible if the proper precautions are taken; the latter it is now proposed to briefly consider.

## Properties and Production of X-Rays.

The X-ray, discovered by Prof. W. K. Röntgen in 1895, is of the same nature as light rays, except that its wave-length is about 10,000 times shorter, so that it is situated beyond the ultra-violet end of the spectrum. The wave-length of X-rays is about $10^{-8}$ centimetres, and their velocity about $3 \times 10^{10}$ centimetres per second; their range of action varies from a few centimetres to over 100 metres at normal pressure and temperature in air.

X-rays are not visible to the eye, and they do not cause fluorescence or illumination of ordinary objects upon which they impinge, except in one or two special cases; for example, when X-rays impinge upon special screens coated with tungstate of calcium, the screens fluoresce, and are therefore used for visual observations.

X-rays are neither reflected nor refracted from surfaces, like ordinary light rays, but pass right through or penetrate into solids, according to their size and density. The degree of penetration varies inversely as the thickness and inversely as the density or atomic weight of the solid.

Materials of high atomic weight, such as lead and mercury, offer the greatest resistance to penetration, and the former is therefore used for screening the operator and certain parts of the object for this reason.

It may be here mentioned that adequate protection of the

operator is necessary, owing to the fact that the impinging of X-rays upon the human body causes severe dermatitis or skin disease, followed by practically incurable cancerous ulcerations; many fatal accidents have been caused by X-ray burns through the omission on the part of the operator to take suitable precautions.

Before proceeding to further consideration of the properties of X-rays, it may be of interest to describe the method of production of the rays.

The most widely used high intensity X-ray tube is that invented by Dr. Coolidge,* and its use first enabled the method of X-rays to be extended to high density materials.

The tube itself is shown in outline, together with its connexions, in Fig. 176, and photographically in Fig. 175.

The vacuum obtained in this tube is about 1000 times better than that of the ordinary X-ray tube, the pressure existing being not more than a few hundredths of a micron (1 micron being $\frac{1}{1000}$ millimetre) of mercury.

No ordinary discharge will occur even when 100,000 volts are applied to the terminals, and in order to render the tube conductive, the cathode, which consists of a tungsten filament wound in spiral form, is electrically heated by means of a battery current of from 3 to 5 amperes, with a potential drop of a few volts. The corresponding temperature of the spiral is from 1700° to 2350° C.

Surrounding the tungsten spiral, and in electrical connexion with it, is a molybdenum sleeve, the function of which is to focus the cathode rays on to the target electrode, which, in Fig. 176, forms the right-hand electrode or anti-cathode. The latter is of comparatively massive form, and is provided with cooling rings, or a water-cooled end, as it becomes very hot in use.

The cathode and anti-cathode terminals, *L*, are connected to the secondary coil of a very high potential induction coil, or to the terminals of a suitable transformer. It is usual

* Of the General Electric Co., Schenectady, New York.

Fig. 175. The Coolidge X-Ray Tube.

to provide a milli-ammeter and spark gap to indicate the current and potential of the main circuit $L$.

The intensity of the X-rays produced by the impingement of the cathode rays on the anti-cathode, depends upon the temperature and the number of electrons passing.

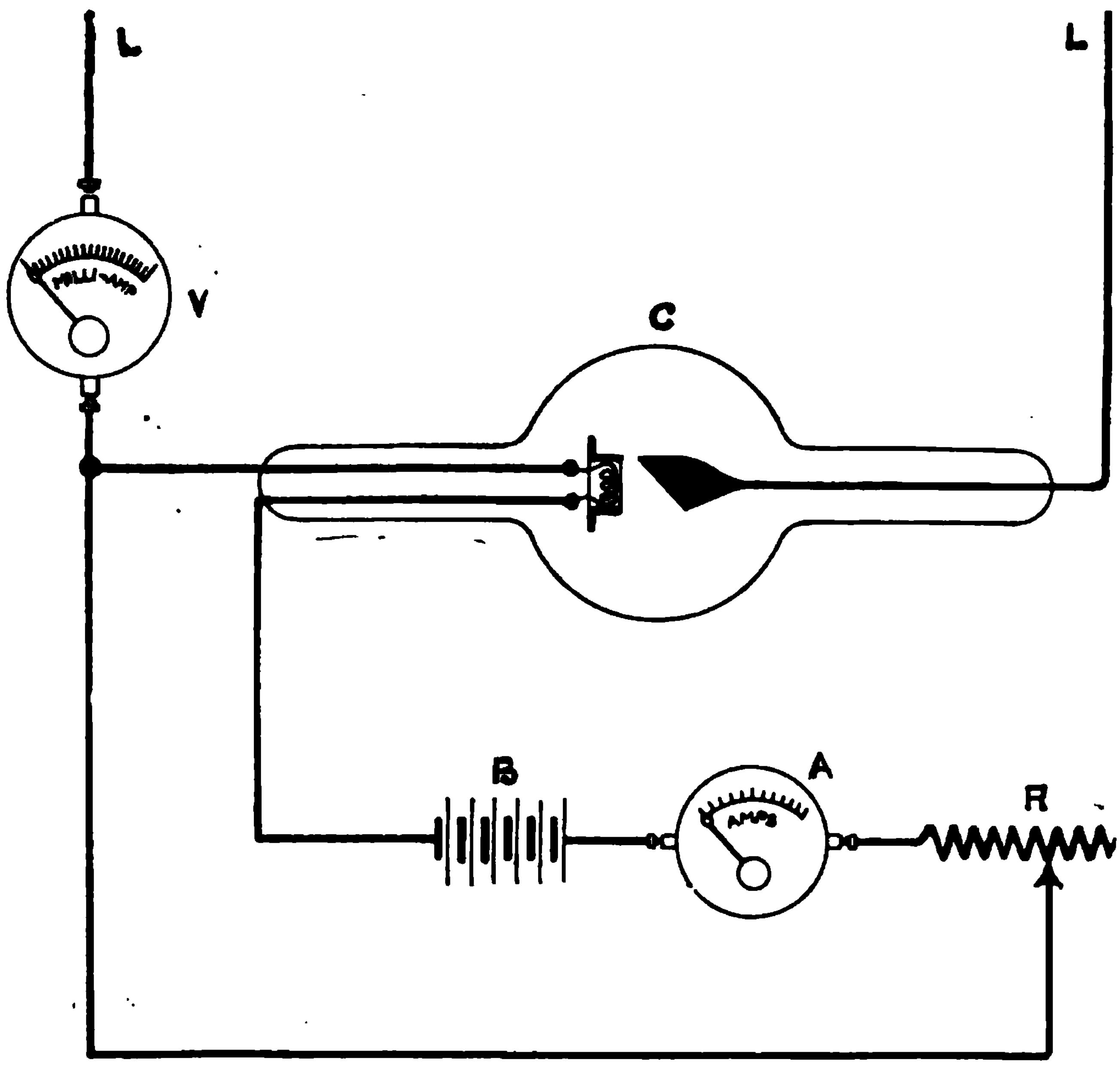



FIG. 176.—DIAGRAM ILLUSTRATING PRINCIPLE OF COOLIDGE TUBE.

It is necessary for ordinary metal work to run upon spark gaps of from 5 to 10 inches, with currents of from 5 to 25 milliamperes and potentials of from 100,000 to 300,000.

Coolidge tubes can be run upon either direct or alternating current, owing to the uni-directional effect of the cathode, and their life varies from a few hundred to over 1000 hours, with proper care.

It is possible to alter the degree of exhaustion in the tube in order to obtain either "soft" or "hard" effects.

**Hardness and Softness of X-Rays.**

After an X-ray tube has been in use for some time it gradually becomes more exhausted, or "harder," and it therefore becomes necessary to soften the tube by letting in more air. The harder the tube, the higher the potential required to "drive" the tube; the degree of hardness affects the penetrative power of the rays; it is usually indicated or measured by the distance apart of two points connected to the same pair of terminals, when so placed that the current occasionally jumps between them.

The intensity of the radiation striking the object under examination is usually taken as proportional to the current passing through the tube (in milliamperes) and inversely to the square of the distance between the source and the anti-cathode or target; the usual distance for metal plates is about 10 inches.

**Typical X-Ray Equipment.**

The general equipment required for the X-ray examination of metal consists of a current supply and control, an arrangement for transforming the available voltage up to the high value required (100,000 to 300,000 volts), the X-ray tube, lead screens for protecting the operator, and the photographic equipment or fluorescent observation screen.

There are two principal arrangements employed in practice for obtaining the high potential required at the X-ray tube electrodes, namely, the transformer, with current rectifier, and the induction coil and interrupter.

For examining metal plates and the like, the induction coil with a spark gap of from 20 to 15 inches, in air, has been found satisfactory; this system is not, however, favoured by some authorities for prolonged exposures or for continuous work, as it has the drawback that the rectifying or kenetron tube, for suppressing the inverse current, becomes "harder" with use, similar to the X-ray tube, and requires frequent adjustment.

Fig. 177 illustrates diagrammatically the arrangement of the transformer type of apparatus, in which *E* is the transformer with motor starter *2E*, *3E* the spark gap, *4E* the

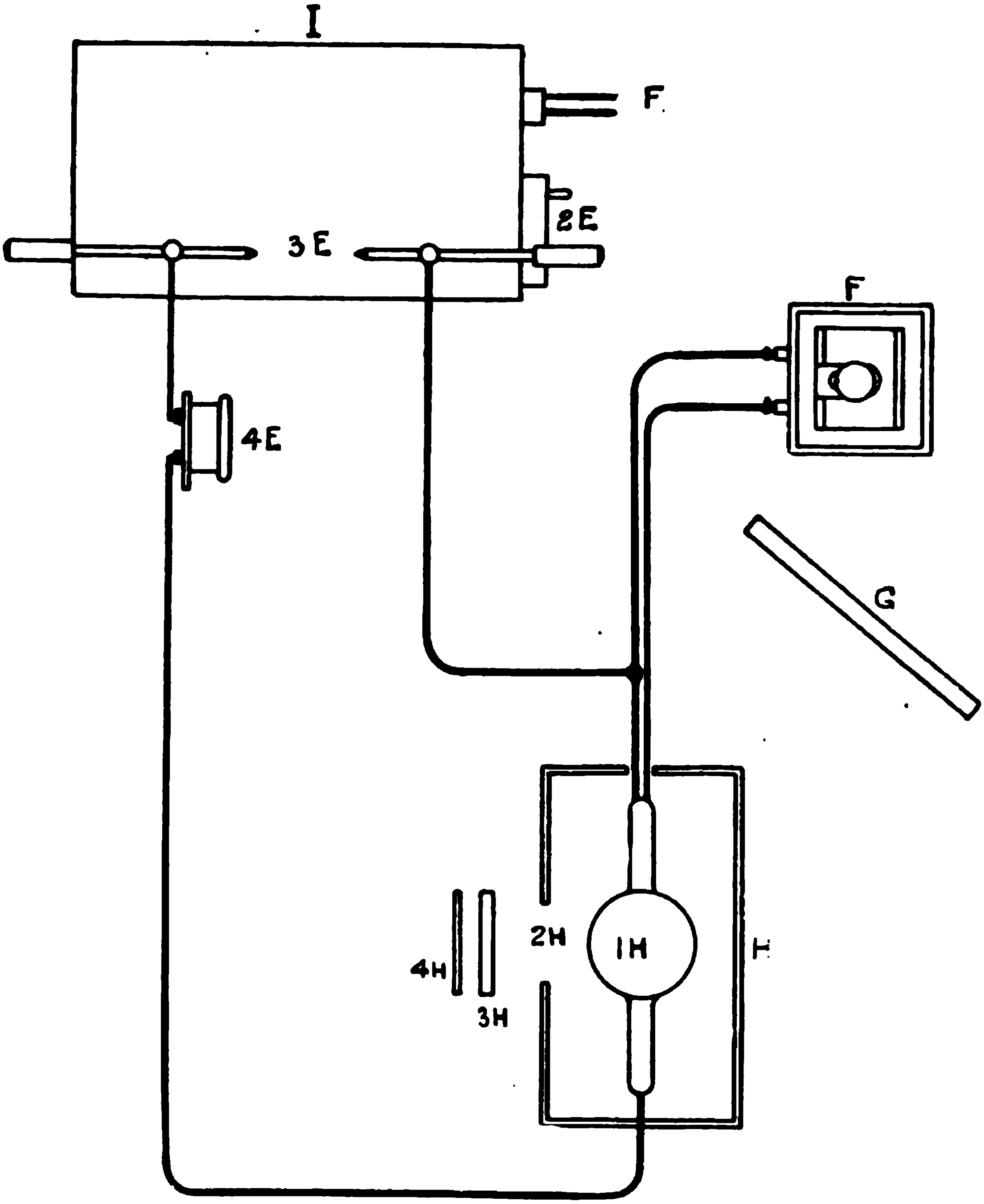



FIG. 177.—SHOWING DIAGRAMMATICALLY A TYPICAL X-RAY EQUIPMENT.

current meter, and *F* the battery stand and control for the filament current of the Coolidge tube, which latter is shown by 1*H*.

The Coolidge tube is placed in a lead-lined box (*H*) provided

with an aperture which allows a beam of the X-rays to escape in the proper direction, so that it penetrates the object $3H$, and affects the photograph plate $4H$.

Between the operator and the Coolidge tube is placed a screen ($G$) consisting of a lead sheet glazed with thick flint glass, which stops most of the rays, for protection purposes.

The lead-lined box is usually arranged so as to be portable, in order that it may be readily slung into position for large objects to be examined *in situ*.

The equipment, when an induction coil is employed, is very similar, except that the previously mentioned rectifying tube and control is required.

High efficiency Wimshurst machines have also been used in some cases, giving voltages up to 300,000, with currents of a few milliamperes, and spark gaps up to about 22 inches.

The number of electrons freed from the anti-cathode, that is, the intensity of the rays, depends upon the temperature of the tungsten spiral, which can be regulated by means of the battery heating current control. The penetrating power of the rays is regulated by means of the potential, as indicated by the length of spark gap; special precautions must be taken to prevent leakage of this high potential current.

### Mounting of the Specimens.

The objects to be X-rayed must be arranged with special care, owing to difficulties which arise from secondary radiation effects.

When an X-ray beam strikes a material particle of any kind the particle itself becomes a source of X-rays, which are projected from it in all directions.

The effect of these secondary rays inside the body itself are not important, as they are absorbed by the other particles around, but when the primary beam impinges upon the surface of the body under examination, the secondary rays tend to fog the photographic plate placed beneath the object, and

unless special care be taken to screen the plate against these rays, fogging may become so bad that the primary ray image disappears.

The strongest secondary radiation occurs where the primary ray strikes the surface of an object at a slight angle ; between about 30° and the normal, no serious production of secondary rays occurs.

Fig. 178 shows a simple example of screening a metal plate *E*, which it is required to radiograph ; the primary rays

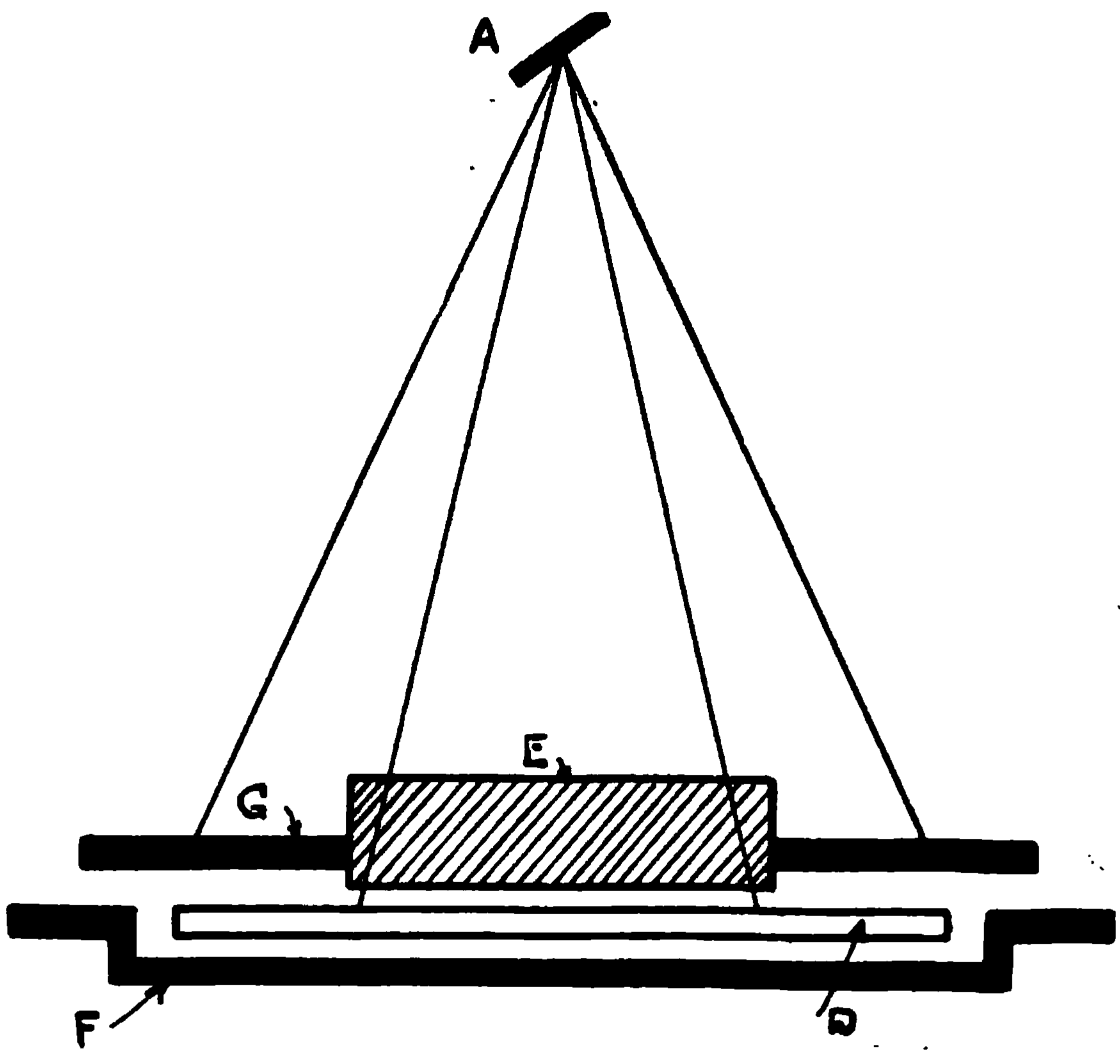



FIG. 178.—METHOD OF SCREENING PLATE.

emanate from the target *A*. The plate *E* is provided with a lead plate screen *G* which masks it, so that no edge-radiations reach the photographic plate *D*. The lower surface of the photographic plate is screened by means of the lead dish *F*.

Fig. 179 illustrates a typical method of screening a specimen by employing mercury for the holes and edges and wax for the awkward cavities or irregular shapes. The whole system is placed upon a sheet of cardboard or aluminium, and the photographic plate is protected, as in the previous example, by means of a shallow lead dish.

In certain cases lead shot may be used in place of mercury, and where the bottom of the object is of an irregular shape, as in castings, paraffin wax may be employed to fill up the irregularities, and to prevent the mercury getting under the object and obscuring the image on the plate ; it is usual to allow an overlap of the lead mask of about 1 inch as a minimum, all round, and the gap between it and the tray must be as small as possible.

For thin metal plates of a few millimetres, the above precautions become unnecessary, and all that is required is a lead mask in front and one behind the photographic plate ; in these cases very short exposures are given, so that the

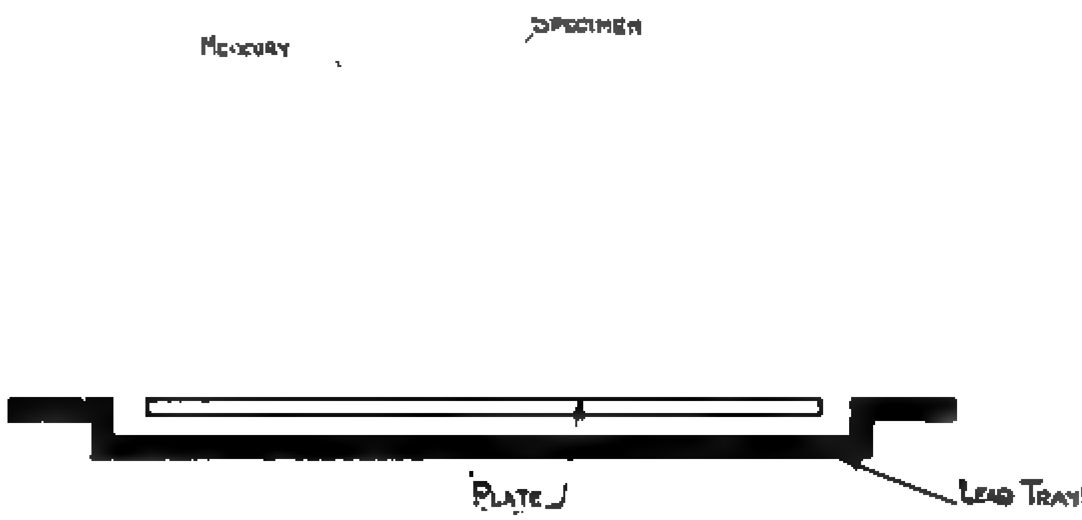



FIG. 179.

weak secondary rays have practically no effect. With thicker specimens, the secondary rays become of increasing importance and special precautions must be taken to guard against fogging.

**Photographic Details.**

At the present time most of the X-ray work upon aircraft and automobile materials is done with the aid of photographic plates ; later developments will, no doubt, enable visual observations to be made, using special fluorescent screens for the purpose. For quantity production material examination this is very desirable. The photographic plates employed are of the highest possible speed, but excellent

results are obtained by using celluloid films coated with emulsion upon both sides. When plates are used, these are placed in holders which also contain intensifying screens which are pressed against the plates.

In the case of double coated films, two screens are used, one being pressed against each side.

The effect of the intensifying screen is to greatly diminish the exposure ordinarily required.

These screens are coated with a salt such as tungstate of calcium, which fluoresces under the action of X-rays, the violet light emitted having a considerably higher actinic value than the X-rays themselves. The plate is therefore affected to a much greater extent than by the X-rays, and the exposure is reduced to about $\frac{1}{15}$ to $\frac{1}{20}$ of its value.

For small objects, instantaneous radiographs of moving parts such as mechanisms can be obtained; in the case of the human body, which does not require intense X-rays, cinematograph pictures can be obtained, showing the action of the heart, kidneys, etc.

Most of the examples met with in engineering practice, however, require appreciable time exposures, depending upon the thickness and atomic weight of the objects.

The following table* shows the exposures required in the case of mild steel plates, at 10 inches from the anti-cathode, and with a 10 inch spark gap—

TABLE CLII.

RADIOGRAPH EXPOSURES FOR STEEL PLATES.

| *Thickness of Plate (inches)* | *Exposures in milliampere-seconds.* |
|---|---|
| 0·25 | 20 |
| 0·50 | 80 |
| 1·00 | 350 |
| 2·00 | 1600 |

For example, in the case of ½ inch steel plate using a current strength of 10 milliamperes, an exposure of 8 seconds is required.

* Messrs. the Cox Cavendish Co.

**General Considerations.**

When arranging objects for X-ray examination, care should be taken to avoid distortion effects in the radiograph " shadow image " due to the obliquity of the X-rays falling on the plate, and to irregularities in the object itself.

The views to be taken of the object should be suitably chosen so as to locate any internal defects.

The relative positions of the plate and the X-ray tube are usually determined by the above considerations ; the distance between them depends upon the necessity of keeping all conductors, or bad insulators, at least 8 to 10 inches from the electrodes or high potential leads.

The object must be properly screened on the lines previously mentioned ; for radiographs of parts of thick objects it is usually sufficient to use two lead screens, one above, with a hole cut in it, and one below the photographic plate.

The X-ray tube should be adjusted so that the current strength of the tungsten spiral circuit gives the correct intensity of radiation, whilst the potential across the electrodes should be regulated so as to give the correct degree of penetration ; to obtain the correct potential the spark gap should be set to the selected distance, and the current turned on with the controls upon the smaller current side. The controls are then regulated so as to give the correct current for the required X-ray intensity when sparking just beginis across the gap ; when this stage is reached the gap points are increased until sparking just ceases, and the current is then switched off. The photographic plate and screen are then inserted in position, and the current again switched on for the given exposure period.

Except for very high potentials, the operator can usually view the apparatus from behind a protective lead screen with a thick glass view hole, or window.

For high potential work, viewing may often be done by using reflecting mirrors inside the leaden chamber.

In conclusion, it need hardly be mentioned that only a

very brief exposition of the subject has been possible, but sufficient information will no doubt have been given to enable the reader unacquainted with the subject to form an idea of the importance and the possibilities of the X-ray method when applied to material examination.

There is, further, little doubt that future developments in connexion with higher X-ray tube vacua intensities and potentials, and in the direction of more sensitive photographic plates and screens for both photographic and visual purposes, will extend the possibilities and applications of the above method.

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